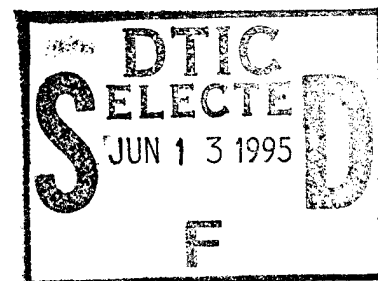# NAVAL POSTGRADUATE SCHOOL
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THESIS

A SIMULATION MODEL OF CARGO HANDLING FOR THE MARS CLASS COMBAT STORES SHIP CONVERSION

by

Michael K. Fabish

December, 1994

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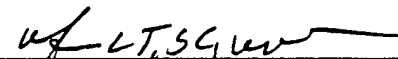
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I. INTRODUCTION

A. PREFACE

The transfer of the MARS Class Combat Stores Ships to the Military Sealift Command (MSC) provides the opportunity for the Navy to significantly reduce end-strength manning and operating costs. The success of this program will be largely dependent upon the ability of the ships to operate with a significantly reduced crew size. To achieve this, a $25 million per ship investment is being made to upgrade the cargo handling system and provide habitability improvements to accommodate the mostly civilian crews. This investment is intended extend the service of these ships well into the 21st century. The USNS SAN JOSE, which is currently in overhaul, will be the first ship of the Class to receive the full cargo modification with the installation of five cargo elevators and two dumbwaiters to replace various conveyor systems.

The importance of this investment is that replenishment at sea directly enhances the ability of the Navy to accomplish its mission by enabling combat ships to remain on station for extended periods. This is the primary mission of all Combat Logistics Force (CLF) ships which are equipped to provide fuel, ammunition, provisions and stores while at sea day or night. Naval Warfare Publication, *Replenishment at Sea,* clearly states the objective: "The goal of underway replenishment (UNREP) is the safe delivery of the maximum amount of cargo in the minimum amount of time" (NWP-14E, Sec 1.1). It therefore is essential that cargo handling operations aboard CLF ships be conducted as quickly and efficiently as possible to support this mission.

The CNO approved the transfer of the MARS Class ships to the MSC on October 4, 1990. This decision was based largely on a 1990 Center for Naval Analysis (CNA) study, entitled "Civilian Manning of Combat Logistics Force Ships: The Potential for Cost Savings". According to this report, an annual cost savings of $9.8 million per ship transferred can be achieved primarily as a result in a reduction of crew size from 446 under Navy manning to 184 including a small detachment of military personnel (MILDET) as proposed by the MSC (CRM 90-130, JUL 1990). One of the reasons cited to explain how the MSC is to operate the ships with such reduced manning levels is given in the CNA report:

The MSC is able to operate CLF ships with much smaller crew sizes in part because skilled mariners are hired. One reason for higher manning levels on Navy vessels is that unskilled recruits must constantly be trained to replace more skilled sailors who only spend a few years in uniform (Rost, Keenan, and Nelson; 1990, p.7).

Even with skilled mariners replacing sailors, improvements in the ship's equipment were required to achieve the required operational capabilities (ROC). The labor intensive nature of operating package conveyors resulting from safety concerns and other operating issues focused efforts on improving the vertical handling equipment. The current conveyor system design is labor intensive for a number of reasons. First, safety considerations resulted in a Naval Occupational Safety and Health (NAVOSH) manual OPNAVISNT 5100.19 implementing a two-man rule for all conveyor operations in addition to a dedicated safety observer. Numerous serious injuries resulting from personnel getting caught in the machinery when reaching into conveyor trunks when placing packages on to the moving conveyor platform prompted this requirement. Secondly, most of the conveyor systems are limited to carrying only small packages, thereby requiring many handlings of individual packages. The elevators, although much slower, are capable of moving standard sized pallet unit loads (40" x 48" x 48") and require no safety observers since the trunk doors close while the elevator car is in motion. Finally, by eliminating the need to assemble pallet loads at the time of the UNREP, personnel who are normally needed to operate the rigging equipment can assist cargo handling efforts. Thus, by replacing the conveyor systems with elevators, a significant reduction in manning is expected:

> Installation of the new elevators by MSC will reduce the cargo handling team to approximately half of the Navy's required team. This manning difference is strictly due to the operating differences between conveyors and the elevators (Procurement Plan, P. 2-3)

Ultimately, however, the success of the transfer program is not just a matter of reducing the crew size. It is the collusion of a new operating environment, the employment of skilled mariners and improved cargo handling equipment that, when combined, will continue the effective service of the ship class under the MSC into the future.

B. ISSUES LEADING TO THIS STUDY

With the replacement of much of the existing vertical cargo handling equipment and the assignment of almost an entirely new crew, as a result of the turn-over of the ship to the MSC, the USNS SAN JOSE faces a significant challenge once it returns to service early in 1995. Without reliable preliminary estimates of the operating capabilities of the new equipment and the resulting effects on the other aspects of the cargo handling operations, the ship is likely to face a long and potentially painful learning process that is typical when attempting to operate new systems. The desire to avoid this by developing a quantitatively-based tool for evaluating the performance aspects of the new system resulted in this study. This thesis is a response to a request by the Supply Officer of the USNS SAN JOSE, Commander Rich Gray, to develop such a tool.

C. OBJECTIVES AND METHODOLOGY

The primary objective of this study is to develop a simulation model to analyze cargo handling operations on the USNS SAN JOSE. The model is intended to be used as a decision support mechanism to evaluate alternatives by predicting the operating characteristics of the new cargo handling system over a range of conditions. Specific aims are:

- Analyze components of the system including elevator lift capabilities, allocation of forklift trucks, and material handling methods.

- Assess the interaction of components (system dynamics) to determine the system's overall operating characteristics.

- Provide the means for modification/expansion of the model to permit future use.

To effectively estimate performance characteristics resulting from the installation of the improved vertical cargo handling equipment, a systems perspective will be used. The advantage of this approach is that cargo handling can then be viewed in terms of all of the components, fully recognizing the integration of events (Blanchard, 1991). Alternative strategies involving changes in methods, resources, and facilities can then be evaluated by looking at the resulting final output performance of the entire system rather than concentrating merely on components of the system. Essentially, this permits a focus

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on the flow of material throughout the system. In this thesis, we develop a simulation model written in the SIMAN simulation language to analyze cargo handling operations on the USNS SAN JOSE. The key characteristics of the cargo handling system are designed into the model to simulate cargo movements supporting underway replenishment. The simulation program is then run under a range of conditions to estimate the operating characteristics of the system. Using various performance measures to evaluate alternatives, suggested material handling methods and allocations of resources will be offered. Proven material handling principles along with the professional opinions of the ship's cargo handling personnel will be used to select initial cargo handling methods for evaluation and as a basis for developing initial estimates for selected input parameters where data is not available.

D. THESIS PREVIEW

Chapter II describes cargo handling and underway replenishment operations and provides a detailed description of the existing cargo handling equipment on the MARS Class ships. Chapter III introduces the concept of simulation modeling and describes the components of the material handling system that are included in the model design. Material handling concepts that are used to establish initial estimates for model inputs and as a guide in selecting alternative cargo handling strategies for evaluation are also introduced. Chapter IV demonstrates two uses of the model. First, an estimate of the vertical lift capability of the 12,000 lb elevators is provided. Second, the model's capability as a decision support tool is demonstrated through the evaluation of initial operating alternatives for a given UNREP problem. Chapter V presents a summary, conclusions, and recommendations.

II. CARGO HANDLING AND UNDERWAY REPLENISHMENT

A. UNDERWAY REPLENISHMENT PHILOSOPHY

AFS 1 Class ships were originally designed to operate along with fleet oilers and ammunition ships as part of an Underway Replenishment Group (URG). Battle forces were to rendezvous with the URG away from hostilities in relatively safe waters to replenish fuel, ammunition and stores before returning to the combat area. This task was very labor intensive which greatly influenced the original design of the AFS 1 Class, resulting in a ship design requiring a manning level of 446 in order to be capable of supplying several ships simultaneously. With the introduction of the AOE concept as a one-stop, multi-product capable ship designed to replace the URG, the time needed to replenish a battle force was greatly reduced. AOEs operating with the battle force were capable of replenishing the combatants on station as required. The mission of the AFS 1 class has subsequently shifted towards being primarily a shuttle ship transiting back and forth between resupply points and the battle force rather than remaining on station. (UNREP Station Reduction Study, 1991)

The following sections describe the original ship design, equipment configurations, and resulting fleet cargo handling practices that evolved over time to support the mission of the AFS. This background provides the basis for designing the simulation program in order to accurately model the important aspects of the cargo handling system.

B. CARGO HANDLING DESIGN

Casual observation of an ongoing UNREP tends to provide a rather simplistic impression of the entire evolution. It appears to be a simple matter of moving cargo from one ship to another. Focusing on only the physical transfer of cargo between ships, however, belies the true complexity of the operation, and obscures any understanding of the degree of coordination and planning necessary to accomplish the task. Testimony to the true complexity of the operation are the numerous equipment configuration changes which were made over a forty-year period while attempting to achieve the cargo handling

goals envisioned in the original design concept.[1]   Many of these changes involved substantial alterations to the ship's design .

The MARS Class combat stores ships were built between 1963 and 1970 by the National Steel and Shipbuilding Company (NASSCO) based on a design developed in the 1950s. The ship's manning and cargo handling systems were specifically designed to provide a cargo breakout rate sufficient to support the maximum achievable transfer rate by connected replenishment (CONREP) to an aircraft carrier to port and a destroyer to starboard, plus a simultaneous vertical replenishment (VERTREP) to another more distant ship (Transfer Manual, p. 1-1). Beginning with the initial design, the intention was to make the transfer rate the controlling event rather than internal cargo handling. To achieve this, an array of equipments including lifts, package conveyors, pallet conveyors, and elevators were incorporated into the design to provide the required vertical lift capability to move cargo up from the holds to the main deck. Horizontal cargo movement is facilitated by a passageway running the entire length of the main deck along the inboard starboard side of the ship with athwartship passageways connecting each of the port CONREP stations.

C. CURRENT CARGO HANDLING SYSTEM

The ship has a total of five cargo holds ranging from three to four platforms deep depending on the location. The holds store refrigerated and frozen foods, dry provisions, bulk materials, ship store items, soda, and general stores (includes repair parts, general use consumables and clothing items). The typical breakdown is:

- 30% refrigerated foods (chill);

- 30% dry food provisions; and

- 40% general bulk materials, repair parts and consumables.

The commodity type and the associated demand level significantly influenced decisions concerning hold configurations, storage aids and material handling equipment.

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[1]Experience gained from construction of earlier ships of the class and subsequent fleet experience resulted in three series of the same basic class. The total number of equipment changes over the past 40 years includes more than 700 ship alterations and other lessor alterations for the MARS Class ships. (Transfer Manual, pp 1-1 thru 1-7).

Generally, the MARS Class uses package conveyors to serve holds containing smaller/low demand material and pallet conveyors to move larger/high demand items that are normally issued in pallet loads. Larger bulk material is moved by elevator. All cargo coming up from the holds is delivered to the main deck where it is subsequently moved by forklift to staging areas or replenishment stations as required. This is the only deck where cargo can be moved horizontally about the ship. The following paragraphs describe the ship's configuration as illustrated in Figure 1.
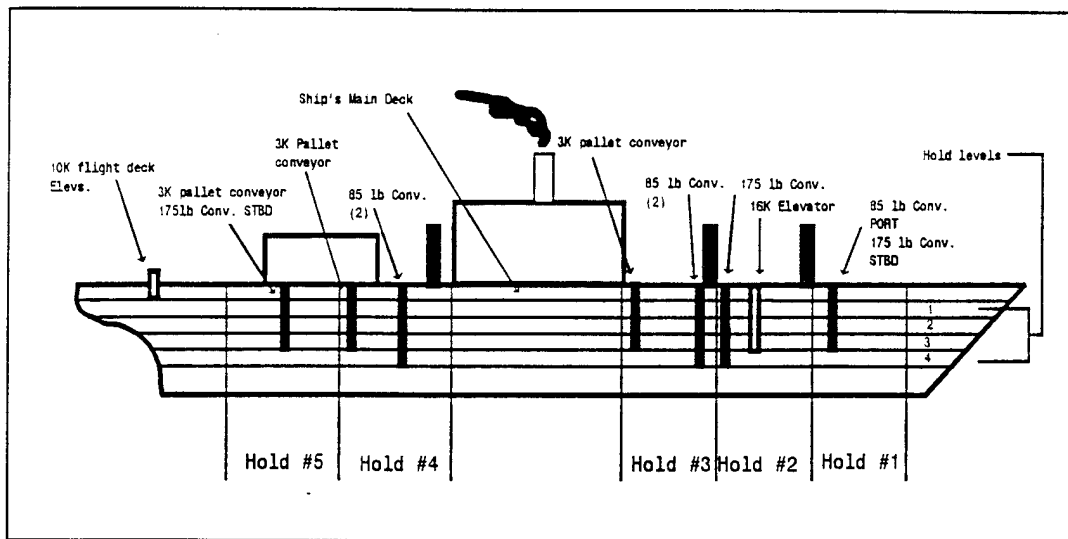
Figure 1. Original cargo equipment arrangement.

The ships's holds are located below the main deck as indicated in the figure. Hold #1 stores small repair parts and other consumables on three levels. Cargo is lifted to the main deck by two small vertical package conveyors where it is palletized and pre-staged. The low volume and general small size of individual parts permit the manual loading of material onto the conveyors. Typical UNREPs will rarely require more than one or two pallets from this hold.

Hold #2 stores large bulk materials on the first three levels. A 16,000 lb elevator serves each these levels and is capable of handling up to sixteen pallets in a single lift depending on the total weight. Cargo is loaded on to the elevator by a forklift operating

on a particular level. Material is typically palletized and pre-staged while in the hold. The fourth level stores primarily flammable products packaged in small cans of up to five gallons. These cans are hand-loaded on to a small package conveyor, then lifted to the main deck for palletizing and pre-staging.

Hold #3 stores refrigerated cargo on four levels each capable of accommodating either chill or freeze products as required. Palletized loads for transfer to the main deck are loaded on the 3,000 lb single-pallet capacity conveyor by forklifts operating on each level. Package conveyors also serve all levels of the hold. Individual packages are manually loaded onto the conveyor and are assembled into pallet loads on the main deck. Pre-staging of freeze and chill products on the main deck or flight deck is not normally done more than two hours prior to an UNREP due to the perishable nature of the cargo.

Hold #4 contains dry or bulk stores (including ship's store items) on AFS 1 through 5. AFS 6 and 7 are also capable of carrying refrigerated stores on the first two levels. A 3,000 lb pallet conveyor serves the first three levels. Two additional package conveyors serve all four levels and are manually loaded. Forklifts are utilized on levels 1 and 2 for loading the pallet conveyor.

The configuration of cargo handling systems for Hold #5 depends on the particular ship. The initial design was for stowage of binnable materials including repair parts and general use consumables. On all ships, the hold is service by an 175 lb package conveyor. On AFS 1 through 5 a second 85 lb package conveyor is also installed while AFS 6 and 7 have a 3,000 lb package conveyor in its place.

D. LESSONS LEARNED

Experience has proven that the vertical lift capability on the AFS 1 Class is inadequate to move cargo at a speed sufficient to maintain the desired transfer rate as stated in the original design concept. A study initiated by MSC concluded "the actual [achieved] transfer rate was approximately 50% of the original system design rate" (*Elevator and Dumbwaiter Procurement Management Plan*, pp. 2-2). A number of factors had collectively contributed to reduce the effectiveness of the cargo handling system. Major among these are a high failure rate of the package and pallet conveyors and the inability of the crew to rapidly move packages and assemble pallet loads with the existing installed equipment.

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Assembling cargo into palletized loads before moving the cargo to the main deck was identified as a key issue in improving the process. Moving the material by individual packages up to the main deck before palletizing is a labor-intensive and inefficient process. The inefficiency resulting from moving small unit loads is consistent with one of the key basic principles of material handling which states, "it has been proven that material handling becomes more efficient as the size of the unit (load) increases" (Sauerbier, 1985, pp 471).

In order to achieve an acceptable transfer rate the only alternative has been to pre-stage the cargo to the maximum extent possible. Material is broken out and moved up to the main deck where it is staged to facilitate the anticipated UNREP sequence and individual customer ship's receiving capabilities and desires. Although this method is highly effective in ensuring all transfer stations are kept supplied with cargo during the UNREP, it has resulted in a significant loss in flexibility. This loss occurs because the volume of material staged on the main deck of the AFS typically hinders any efforts to subsequently rearrange the cargo. Leadtime is also increased since customers must transmit their requirements further in advance to allow the added time needed to pre-stage cargo. The concept of rapid and selective breakouts as envisioned in the initial design concept, where material is broken out for delivery at the time of the UNREP, has proven to be an elusive goal.

E. PHASES OF CARGO HANDLING OPERATIONS

Cargo handling is accomplished in two distinct phases. The first phase occurs several days prior to the UNREP where material is broken out and pre-staged primarily along the main deck. The relatively low urgency of this operation permits frequent adjustments as warranted to accommodate conditions and limitations of material handling equipment. Planning is also facilitated since it does not have to consider nearly the number of interrelated events that must occur at the time of the actual UNREP. Events can therefore be carefully planned and executed almost in isolation with relative ease.

The second phase begins just prior to the start of the UNREP when cargo is moved up to the flight deck and adjacent to the Replenishment at Sea (RAS) stations. The prime focus of material handling efforts at this time is to stage the material as close as possible to the expected transfer area. The exception is refrigerated cargo which must

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be kept in the holds until just before the start of the UNREP. It is therefore not uncommon to be still moving refrigerated stores up from the holds while the UNREP is in progress. Since refrigerated cargo is most frequently transferred via VERTREP (vertical replenishment is the transfer of material between ships by helicopter), it must be moved aft along the starboard aisle to the aft portion of the main deck where it is netted before being sent up to the flight deck.[2] If refrigerated stores are to be transferred by CONREP the cargo will be sent directly to the designated RAS station staging area.[3] CONREP is the transfer of cargo by a wire and sling system between ships while they steam alongside one another.

Cargo designated for transfer via CONREP can be staged inside the ship along the starboard aisle on the main deck or in athwartship passageway areas. Weather permitting, cargo can also be staged outside next to the designated RAS station ready for transfer. However, this is typically not done until just prior to the UNREP. The largest staging area is the aft portion of the main deck called, "after cargo" or "aft cargo", which is capable of holding several hundred pallets. It has the added advantage of being close to the elevators serving the flight deck. Typically 60% of all cargo is transferred via VERTREP during a large UNREP.

F. PLANNING CARGO HANDLING STRATEGIES

The difficulty in designing a cargo handling plan sufficiently robust for the wide range of UNREP scenarios typically encountered has forced each ship to rely on locally developed strategies. These strategies are based largely on the corporate knowledge of the ship's key personnel and training received during Refresher Training (REFTRA) or Ship Qualification Trails (SQT). Cargo handling plans and procedures therefore have evolved by an iterative process based predominantly on learning experience. Currently no model or tool is available specifically to aid in planning for cargo handling operations.

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[2] Aircraft carriers sometimes request to receive chill cargo by CONREP forward since this is closer to their refrigerated storage.

[3] RAS stations are the areas on the main deck where the rigging equipment is located that physically transfers the cargo along a tensioned wire connected between the supplying and receiving ships. Occasionally the stations are referred to as CONREP stations rather than RAS stations.

NWP-14E (Replenishment at Sea) does provide a listing of the general capabilities of UNREP equipment and some detailed operating instructions for major equipments. As a planning tool, however, it does not provide specific guidance other than planning estimates of transfer rates along with some descriptions of environmental conditions that are likely to affect these rates. Five key environmental factors impacting underway replenishment operations that are typically cited include:

- Crew experience of the transferring and receiving ships;

- Number and type of receiving ships;

- Sea state and distance between ships;

- Size of the UNREP and commodity breakdown;

- Material condition of transfer rigs and associated material handling equipment of both the transferring ship and the receiving ship;

The focus of these factors is primarily on external movement and therefore is of little assistance when considering internal cargo handling strategies. As a consequence, the challenge remains to develop an internal material handling plan that effectively and efficiently uses installed equipment and resources so as to provide an uninterrupted supply of cargo to all transfer stations. Accomplishing this is fundamental to the success of ship's mission of rapidly transferring of cargo.

G. IMPROVING CARGO HANDLING

The Chief of Naval Operations approved the transfer of the MARS Class ships based on an MSC proposal. MSC developed this proposal following the recommendations of several studies focusing on ways to reduce manpower requirements aboard the AFSs. Under tasking from MSC, the Naval Weapon Systems Engineering Station (NAVSWESES) in Port Hueneme, CA conducted three studies; the "UNREP Manpower/Maintenance Reduction Plan", dated June 1991, the "Cargo Handling System Study", dated June 1991, and the "Automatic Ram Control Study" also dated June 1991. The need to achieve the desired transfer rate with reduced manning focused the studies on three key issues. They were unit load handling, cargo pre-staging, and vertical lift capability. The following is a

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summary of the key recommendations of these studies as stated in the *MSC Elevator and Dumbwaiter Procurement Management Plan*:

- **Pallet Fabrication** - The fabrication or building of unit loads (pallets) is a critical path item in achieving the required transfer delivery rates.

- **Cargo Pre-staging** - When operating under the MSC ... up to 80% of the cargo will be typically pre-staged on fully loaded pallets prior to a replenishment operation. The loaded pallets will be stowed out of the weather to the greatest extent possible on the main deck and flight deck to await transfer. Refrigerated cargo ... will not be moved to the main deck until two hours prior to the replenishment operation.

- **Vertical Lift Capability** - The time required to fabricate pallets in preparation for transfer is dependent on the efficiency and speed of the vertical cargo [handling] system. The efficiency and speed of the new system will require MSC to begin pallet building several days in advance of replenishment operations. (Procurement Management Plan, p. 2-2)

The essence of the plan is basically to build palletized loads as soon as possible, handle only palletized loads wherever practical, and make the maximum use of pre-staging. Improving the vertical cargo handling capability is the essential element of the plan. With the exception of handling small parts in holds #1 and #5, and flammables in the lower level of hold #2, all material movement up from the holds is to be accomplished in palletized loads by elevators.[4] The elevators will allow for the assembly of pallets within the holds while providing rapid lift capability and thereby eliminating the need to palletize loads at the time of the UNREP.

The new cargo handling arrangement for T-AFS-7 is presented in Table 1.[5] Holds #1 and #2 will be serviced by 3,000 lb elevators capable of lifting one pallet each. Holds

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[4] Not all the MARS Class ships are to receive the complete cargo equipment upgrade. AFS 1, 3 and 5 are to receive only two 12,000 lb elevators serving holds #3 and #4 (Elevator and Dumbwaiter Procurement Management Plan). Future reductions in the scope of the modifications might also result due to funding considerations.

[5] Elevator No. 2 is the 16,000 lb elevator serving hold #2 shown in Figure 1 and is not part of the equipment upgrade. Therefore, this elevator is not mentioned in Table 1.

#3, #4, and #5 will be serviced by 12,000 lb elevators capable of carrying three pallets each. Additionally, 500 lb dumbwaiters which can accommodate only packages, will provide redundancy in holds #4 and #5 . Although the dumbwaiters are far less efficient than the vertical conveyors systems because they use only a single moving platform which must cycle up and down, they are also less labor intensive since the access doors must be closed to operate the system eliminating the need for safety observers. The elevators are all rated to travel at 100 ft per minute and the dumbwaiters are rated at either 60 or

Elevator No.	Hold Location	Weight Capacity	Unit Load	Decks Served
1	Hold #1, AFT	3,000 lb	1 pallet	4
3	Hold #2, AFT	3,000 lb	1 pallet	5
4	Hold #3, FWD	12,000 lb	3 pallets	5
5	Hold #4, AFT	12,000 lb	3 pallets	4
6	Hold #5, FWD	12,000 lb	3 pallets	3

Table 1. New elevator installations for AFS-7 (Elevator and Dumbwaiter Procurement Management Plan, Appendix B).

100 feet per minute depending on the ship's installation. These figures represent only the maximum travel speeds of the equipment. (Elevator and Dumbwaiter Procurement Management Plan, p. 2-5)

The final impact of the new elevators and dumbwaiters will be dependent upon more than just the increased lift capability of the vertical lift equipment. The flow of material also involves forklift operations, staging operations, priority assignments, and other material handling planning issues. The focus of this research is therefore, to capture the "total" effect of the improved vertical lift capability and identify methods and resource

allocations which will be advantageous in terms of meeting the ROC both efficiently and effectively. Lacking a real system to experiment with, simulation modeling offers a cost effective method of experimenting with a system that has never been operated (Apple, 1972).

III. SIMULATION MODELING

A. DEVELOPING A SIMULATION MODEL

A simulation model is a representation of a process or system over time that uses generated data to simulate the operation of the real system. The model is based on assumptions about the system that are expressed as relationships between entities, the objects of interest. By observing the output of the model inferences, can be made concerning the characteristics of the system. The most obvious advantage of using simulation models is that it allows for studying the effects of alternative decisions without ever operating the real system (Banks, 1984). Perhaps an even more important aspect of using simulation modeling is the ability to take a systems perspective. The advantage is; "the systems approach tries to consider total system performance rather than simply concentrating on the parts; it is based on the recognition that, even if each element or subsystem is optimized from a design or operational viewpoint, overall performance of the system may be suboptimal because of the interactions among the parts" (Pegden, Shannon, and Sadowski; 1990, p. 4).

With the installation of the three-pallet capacity 12,000 lb elevators on the USNS SAN JOSE, it seems reasonable to expect a significantly increased lift capability in terms of the rate at which cargo can be moved to the main deck. However, the effects on the other components of the system are uncertain. Along the main deck where competition for space is keen the added congestion due to the increased flow of material up from the holds could conceivably offset any gain that might be realized by the improved vertical lift capability or even worse, actually reduce the ship's overall ability to rapidly move cargo. Determining the right sequence of events, the right time to begin, and the right allocation of resources is an immensely complex problem for the ship. Such difficulty often results in best-guessing as a pragmatic approach. However, as this research suggests, this is not the only alternative.

B. SIMULATION MODEL DESIGN AND CONCEPTS

The model developed for this research uses the SIMAN simulation language. SIMAN (SIMulation ANalysis) is a commercially available general purpose simulation language that uses a logical modeling framework to aid in programming. It segments

problems into "model" and "experiment" components. The model describes the physical elements of the systems in terms of the machines, resources, storage points, material flow, and their logical relationships. The experiment specifies the conditions under which the model is run including elements such as initial conditions, resource availability and statistics to be gathered for the purpose of evaluating the system's performance. Once the model and the experiment have been defined, the program is run to generate simulated responses of the system. The output data can be stored, graphed, used to prepare histograms, confidence intervals or displayed using presentation-quality graphics packages. (Pegden, Shannon, and Sadowski, 1990)

Designing a useable decision support model requires a degree of balancing between simplicity and precision. Simplicity aids in usability by improving conceptual understanding of the model's functions. However, it also requires generalizations to be made resulting in some loss of accuracy. Ultimately the model must only behave sufficiently similar to the real system to allow valid conclusions to be drawn. Attempting to go beyond this point by including incidental aspects of the real system that do not materially affect the performance of the system may have undesired effects. In fact, more complex models "[are] likely to contain undetected bugs that can introduce errors of a much larger magnitude than would be introduced with a simpler model" (Pegden, Shannon and Sadowski,1990, p. 36). In an effort to reduce the likelihood of model induced errors and erroneous conclusions on the part of users, the model design offered in this research purposefully tends towards minimizing complexity. This is accomplished through a selective simplification process by combining or eliminating lessor elements that are unlikely to have significant impact on the performance of the system.[6] When the primary objective is to compare alternatives such an approach is justified since the concern is with the relative performance of the system. (Pegden, Shannon, and Sadowski, 1990)

1. Model Scope.

Since the major improvement to the material handling system on the USNS SAN JOSE are the three 12,000 lb three-pallet capacity elevators serving holds #3, #4, and #5, the scope of the model presented is limited assessing the performance of these elevators

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[6] This is an application of Parades Law which asserts; "in a collection of entities there exists a vital few and a trivial many" (Pegden, Shannon, and Sadowski, 1990, p. 16).

and their impact on main deck cargo forklift delivery operations. The assembly of material into palletized loads and the pre-staging of the pallets within the holds is assumed to have already occurred. The system, with respect to the model, consists of the elevators, facilities in terms of space, and the forklifts needed to move the cargo from the holds to user specified destinations which may be staging areas, RAS stations or the flight deck. [7] Specifically the components of the system include:

- Forklift elevator loading operations in holds #3, #4, and #5.

- The vertical lift of cargo to the main deck from these holds via the new 12,000 lb capacity elevators.

- Elevator loading and unloading operations.

- Movement of cargo by forklift along the main deck considering competing access to staging areas and the restrictive physical features of the forklift operating areas.

Excluded from consideration is material movement from holds #1 and #2. This was excluded from the model since this material typically accounts for only a small percentage of the total UNREP size. This material is also normally pre-staged and therefore will have little indirect impact on the performance of the system under consideration.

2. Selection of model type.

A dynamic discrete-event simulation model is used in this thesis. Such models are often used for material handling problems since they provide the ability to look at the state of the system at selected intervals (Law and Kelton, 1991). The ability to spot bottleneck problems that reduce the overall performance of the system is the reason this approach was selected. In the case of material handling problems, where material flow is an important consideration, this is particularly advantageous.

The model also employs a terminating system design, stopping at time T_E when the last pallet to be moved reaches its destination because the object of interest is a single UNREP operation. The model can then be used to predict the time required to

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[7] The use of the model in the scenarios presented in Chapter IV is limited to cargo movement from the elevators at holds #3 and #4 to after cargo. The model design is actually more flexible, however. Other destinations can be easily added as desired.

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move a specified amount of material and therefore offers a method to measure and evaluate alternatives or determine the system's capabilities. An additional advantage of this approach is that it provides certain statistical properties that are beneficial.

3. Assumptions

The assumptions of the model are embodied in the model frame of the program. The execution of the program must follow along without deviation. Therefore the model can only make "decisions" that are expressly present in the logic. The assumptions are detailed in the sections that follow describing the model. Key general assumptions are:

- Tasking of resources is based on user assignments specified at the beginning of a simulation run. Emerging conditions will not alter tasking or sequences without user intervention.

- The default priority rule is first-come-first-serve for all resources. Immediate access to the next pallet to be served is always assumed.

- The arrival of a pallet on the main deck is instantly communicated to the first available resource (forklift) assigned to move that pallet.

4. Input variables.

The simulation of a system requires inputs which are random variables to be defined by a specified probability distribution with estimates of its appropriate parameters. During a simulation run, random variates are generated based on the underlying distribution. Two basic methods are suggested to determine the parameters and associated distributions:

- Collect data from an existing source. Using standard techniques of statistical inference a distribution is selected which "fits" the data. Hypothesis testing can be used to determine the goodness of fit.

- Use a heuristic approach for choosing a distribution in absence of any data along with expert opinion to estimate input variables.

Once the USNS SAN JOSE becomes operational, initial data can be used to determine input variables for the purposes of evaluating alternative cargo handling plans. This is the preferred method since it eliminates the need for extensive subjective estimates. It also tends to reduce the need for extensive sensitivity testing.

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As a starting point two common heuristic approaches will be used to define parameters and distributions of the input variables. Although both approaches require some subjective judgement, they do have the advantage of introducing variability into the model. This is an important aspect of simulation modeling since variability can have considerable impact on the outcomes of the model. Many measures of performance for simulated systems depend heavily on the probability of an extreme event occurring. Specifically, Law and Kelton (1991) state: "in general, the variances as well as the means of the distributions determine the output measures of queuing-type problems." [8]

The simplest approach is to estimate only the range of values for an input. The assumption is that only a maximum (b) and minimum (a) value can be reasonable estimated and that any value along the interval [a, b] is equally likely. The uniform distribution is commonly recommended when given only a range however it is not necessarily the best choice (Pegden, Shannon, and Sadowski, 1990).

If both a range is given as well as an estimate of the most likely value then a triangular distribution may be preferred. It has the advantage of being convenient to use since it requires only three estimates, is mathematically simple, and is unimodal.

5. Model output variables.

The probablistic nature of the input random variables and the interaction of events and service times result in many sources of random variation within the model. Consequently, the output statistics of the model are functions of random processes and therefore are also random variables (Pegden, Shannon, and Sadowski, 1990). The outputs are subject to sampling error because of this so both a point estimate and an interval estimate of the output parameters are appropriate. Without an interval estimate there is no indication of the amount of error resulting from the random process nature of the model and subsequently no basis is provided for interpreting the accuracy of the estimate. Interval estimates (typically referred to as confidence intervals) are therefore beneficial since they provide an estimate of the possible error associated with specifying a particular value of a parameter.

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[8] The presence of variance considerably complicates even the simplest of problems.

A point estimator of an output parameter is given by:

$$\hat{\theta} = \frac{1}{R} \sum_{i=1}^{R} Y_i \, ,$$

and Y_i is the *ith* observation given in the simulation output. *R* represents the total number of replications in the simulation, each ending at time T_E.

Point estimators given in Chapter IV including mean operating times, average queue sizes, and resource utilization percentages are calculated by this formula. Determining confidence intervals for the true population means using typical statistical techniques requires that the sample means of the output variables be independent and identically distributed. Since autocorrelation is present in most simulation output data this is not typically the case. To overcome this, independent replications are used with a different random number stream selected at the start of each replication along with and independently chosen initial conditions (which includes the case that all runs have the identical initial conditions)" (Banks and Carson, 1984, p. 421). Confidence intervals can then be constructed to provide a specified likelihood that the range contains the parameter's true value. For the confidence intervals given in Chapter IV, the procedure provided in the SIMAN package was used. The details of this procedure are described in e.g., Law and Kelton (1991, p.556).

a. Performance measures.

Making inferences concerning the performance of the system requires a selection of output variables that are capable of measuring desired aspects of the system. The nature of material handling problems focuses attention on material flows. Therefore, the ability to detect bottlenecks, determine utilization of resources, and measure the output of the system is important. These are the means used to evaluate alternative strategies and predict performance in the model. The four measures of performance included in the model are:

- Throughput: the number of pallets handled per time period.

- Cycle time: the length of time required for a pallet to reach its destination.

- Queue size: the average number of pallets in a staging area.

- Utilization: percentage of time over a specified period that a resource is utilized.

Throughput and cycle time will be used to measure the speed of cargo movement methods. Queue size and utilization are used as measures of efficiency since they are indicators of imbalances in the system. As efficiency measures they offer a starting point in considering improvements to the system.

C. DESCRIBING THE MODEL COMPONENTS

The following sections provide a detailed description of the components of the cargo handling system included in the model. The description defines the system and its boundaries, thereby establishing the relevant constraints and the variables of the model. To aid in this, the system is first divided into subsystems in an effort to simplify model development and to ultimately improve its ability to accommodate changes which will be needed to evaluate proposed alternatives. It also helps simplify initial allocation decisions and subsequent analysis of functional interfaces. The division of cargo handling into subsystems is a natural process since the real system, in fact, consists of a series of related events which must share resources.

The internal cargo handling features considered in this research can be divided into two subsystems. The first involves the vertical movement of cargo from the holds to the main deck via the newly installed elevators. Once on the main deck, the material must be moved to designated RAS stations or other specified staging areas. The second subsystem therefore concerns the delivery of cargo by forklift along the main deck.

1. Vertical cargo lift.

The vertical lift rate of installed equipment is essentially determined by three events; loading, unloading and equipment cycle times. These events represent random input variables since the actual times are uncertain. Estimates of these variables require consideration of numerous environmental conditions present in the holds and other controllable and un-controllable factors. Generally, the cramped conditions of the holds severely constrain forklift movements and therefore proper material handling methods will have a significant impact on the efficiency of operations. The most critical movements occur when the forklift operates inside of the elevator car. With only a few inches of

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clearance on either side the forklift operator must deftly maneuver to pick-up or place a pallet while also negotiating the gap between the elevator car and the deck without upsetting the load. This will be no simple task.

The 12,000 lb elevators serving holds #3, #4, and #5 represent the most significant change in the ship's installed cargo handling equipment. Capable of moving up to three pallets of material at a time they are expected to significantly improve the vertical lift capability in the ship's holds. All elevator movement is controlled from the master station located on the main deck. The elevator car can be called to or dispatched to any deck only from this station. Upon arrival of the car at the designated level, the trunk doors open automatically. However, the elevator car is also equipped with a gate which must be manually opened and closed. The trunk doors are closed by the operator activating a control at the elevator's location. This auxiliary station has various indicators to show the status of the elevator and a button to close the trunk doors.

Elevator operations therefore require a coordinated effort between the operator at the master control panel and the operators on each level in the hold to ensure the elevator is dispatched promptly when ready. Additionally, the sequence of the evolution must be clearly communicated to all personnel in terms of the priorities of cargo movement to preclude avoidable delays.

Operating at the rated speed, the elevators travel at 100 ft/min (Elevator and Dumbwaiter Procurement Management Plan). With a typical height between decks of 15 ft, it will take approximately 9.0 seconds for the elevator to travel between levels without stopping.[9] By adding the time required to level-out (includes deceleration when stopping), accelerating when starting, opening and closing the doors, and dispatching the elevator, the total elevator cycle time can be determined.

a. Model elements.

The model requires estimates for forklift loading and unloading times for each pallet loaded or unloaded from the elevator. This defines the utilization time of the forklifts dedicated (a basic assumption) to these functions and delays the release of the elevator appropriately. The speed and the distance traveled by the elevator is based on

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[9]The actual height between decks varies moving aft from the bow.

the design specifications provided in the contract and is incorporated in the model as a constant. These values can be changed in the program, however, if desired. An additional input value representing a composite estimate of the delay in the movement of the elevator besides the transit time as previously mentioned is required. Initial estimates for all input variable values are provided in Appendix B.

2. Main deck cargo movement.

Given the wide aisle running the length of the ship, moving cargo along the main deck would seemingly be a simple matter. In practice, however, frequent interruptions occur as forklifts, people, and other events impede the flow of cargo. Congestions that occur tend to expand rapidly due to space constraints and communication problems. Forklift transit times can be expected to display considerable variability as a result.

Modeling the movement of forklifts is complicated by the infinite number of resource allocations and task assignment rules. It is therefore necessary, as a simplifying assumption, to specify explicit forklift assignments, thereby restricting their function to a given task at the beginning of a simulation run which can not be altered during the simulation. Figure 2 on the following page provides a diagram of the major routes and distances along the main deck that are typically used when delivering cargo from holds #3, #4, and #5. The scenarios presented in Chapter IV, however, consider only cargo movement from the main deck elevator staging areas to the after cargo staging area. For hold #3 this is a total distance of 270 feet (15 + 150 + 10 + 60 + 35) one way. For hold #4 the distance is 115 feet (10 + 10 + 60+ 35) one way.

With the installation of 12,000 lb elevators for holds #4 and #5 forty feet of the main deck starboard aisle is narrowed to a single lane. This presents the potential for frequent delays while forklifts compete for access to this aisle. More serious delays can result if the aisle is blocked for an extended period by forklift failures or overturned pallets. The model includes narrow aisle logic to limit access to one forklift at a time along this portion of the aisle for a distance of 60 feet (40 feet plus ten additional feet on either side for merging traffic into a single lane). This is the only delay included in the model. Serious delays are not considered.
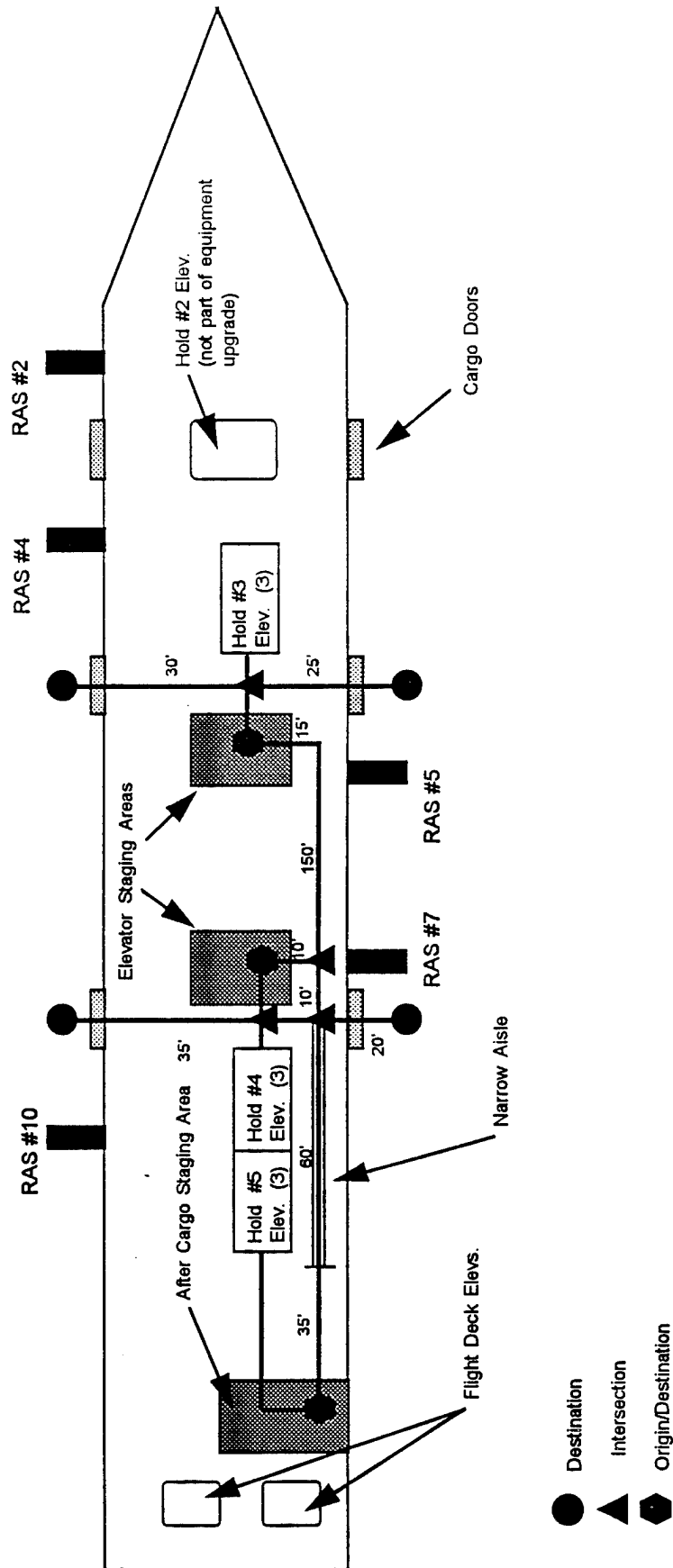
Figure 2. Main deck layout for forklift paths on the USNS SAN JOSE.

a. Model elements.

Two estimates are required for main deck forklift operations after a pallet has been removed from an elevator and placed on the deck next to it. First, forklift speed estimates between major junctions must be provided. Secondly, estimates are required for pallet pick-up and drop-off functions to account for time spent performing staging operations. Initial estimates for these values are provided in Appendix B.

D. RUNNING THE SIMULATION MODEL

The execution of the model program is a rather complex matter. Therefore an overview describing the process is warranted. The three key steps of the process are briefly summarized in Figure 3. The first step establishes the conditions under which the model is run. This includes specifying the number of pallets to be moved by level, the number of pallets carried per lift, and the sequence of lifts. Secondly, estimates for forklift operating times (includes sperate estimates for elevator loading, unloading, main deck forklift speeds, and other basic forklift movements) and elevator delays (excludes actual elevator transit time) as previously discussed. The final step is to run the simulation program under a variety of conditions (varying the data given in steps one and two) while gathering statistics for analysis from the results of the simulation. In Chapter IV this format is used to present the selected scenarios in order to demonstrate the simulation models developed in this research.

E. MATERIAL HANDLING PRINCIPLES

Material handling involves a high degree of human activity therefore individual performance will affect the overall performance of the system. Ballou (1992, p. 585) suggests: "good practices around the basic system design remain the backbone of good materials handling. This comment provides an excellent reminder that there are two components that will largely determine the performance of the new cargo handling system, the system and the method. In the next section the key issues involved in the material handling functions will be presented.

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┌─────────────────────────────────────────────────────────────┐
│  ┌─────────────────────────────────────────────────────────┐ │
│  │ Model Initiation                                        │ │
│  │                                                         │ │
│  │   Set pallet breakout quantity and priority rule by hold level. │ │
│  │   Select route and destination for cargo.               │ │
│  │   Establish forklift assignment rules.                  │ │
│  │   Assign input variable parameters or accept default values. │ │
│  │                                                         │ │
│  └─────────────────────────────────────────────────────────┘ │
│                            ↓                                  │
│  ┌─────────────────────────────────────────────────────────┐ │
│  │ Model Execution                                         │ │
│  │                                                         │ │
│  │   Cargo is loaded onto the elevator per specified sequence. │ │
│  │   Cargo is moved to main deck by the elevator.          │ │
│  │   Cargo is unloaded from the elevator and placed in adjacent staging area. │ │
│  │   Main deck forklift/route assignments are made based on destinations. │ │
│  │   Statistics are gathered for specified performance measures. │ │
│  │                                                         │ │
│  └─────────────────────────────────────────────────────────┘ │
│                            ↓                                  │
│  ┌─────────────────────────────────────────────────────────┐ │
│  │ Model Output                                            │ │
│  │                                                         │ │
│  │   Summary statistics are displayed for total UNREP time, utilization of │ │
│  │   forklifts and elevators, and queue lengths at staging areas and awaiting │ │
│  │   resource allocations.                                 │ │
│  │                                                         │ │
│  └─────────────────────────────────────────────────────────┘ │
└─────────────────────────────────────────────────────────────┘
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Figure 3. SIMAN simulation model program flow.

1. Forklift truck operations.

Forklift operating times impact cargo handling efforts during all phases of the UNREP including during both pre-staging and the actual UNREP since all pallet movements within the holds, on the main deck, and on the flight deck are accomplished by forklift. Operating on ships, and particularly in the holds, movements are often hampered by unfavorable conditions such as crowding, poor lighting, bad traction and delays caused by bottlenecks. The variability of operating times can therefore be considerable and subsequently will have a significant impact on the overall efficiency of the material handling system. Accurately estimating forklift operating times is a critical step as a result.

Two sources are used to develop initial estimates for forklift operating times. The first is based on time study experiments conducted by the USNS SAN JOSE MILDET

using the ship's forklifts in a number of experiments in a warehouse. A description of the experiments and the results are given in Section A of Appendix B. The second is based on standard data (see Section B of Appendix B) obtained from a series of times studies done by the Yale & Towne Manufacturing Company and the Wharton School, University of Pennsylvania (Apple, 1972). In both cases times represent estimates under ideal conditions where the forklifts operate in benign environments. Before these times can be used allowances must be applied in order to recognize that other than ideal operating environments commonly exist on the ship.

In a study conducted by the Materials Handling Division of the Yale and Towne Manufacturing Company and the Wharton School, University of Pennsylvania, three sources of unavoidable delays and interruptions were specifically identified that will typically influence forklift performance. These were; human factors, mechanical conditions, and operating factors. Appendix C contains a complete list of the variables associated with each of the categories with suggested allowances for adjusting standard times. Applying allowances is necessarily a subjective matter since many of the factors are not directly quantifiable without extensive experimentation in the real operating environment. Therefore, a logical recourse is to use a composite value which conceivably will improve the overall accuracy of the final value through the averaging of the numerous factors. In Chapter IV where the estimates of the forklift times are used in two presentations of the model, this procedure is used.

2. Staging operations.

Staging is also an important material handling function on the ship since it forms the bridge between sequential events and impacts directly on forklift operating times, a critical variable. Generally, staging is done for the purpose of improving the efficiency of operations. However, it requires increased handling and therefore should only be used when necessary. Careful consideration must therefore be given to staging operations because of its potential impact on the systems performance. Two primary factors to be considered are, ease of access to the pallets (for forklifts) and distances. Paths to staging areas should be short and direct, avoiding convoluted paths and competition for space with aisles, other forklifts or equipment.

IV. SIMULATION OF CARGO HANDLING OPERATIONS

A. INTRODUCTION OF THE SIMULATION MODELS

Central to all planning concerning cargo handling will be the vertical lift capability of the elevators. The performance of the 12,000 lb elevators will largely drive both the timing and the resource requirements of cargo handling efforts. Estimating the lift rate of the elevators is therefore a critical requirement for developing strategies to effectively utilize available manpower and equipment. Thus, the analysis of the USNS SAN JOSE cargo handling system will be addressed in two parts. First, the performance capability of the 12,000 lb elevators will be estimated using a simulation model to simulate elevator operations. In this model the total time required to lift a specified number of pallets up from the various levels of the ship's holds to the main deck is used to predict the vertical lift rate of the elevator. Secondly, the model is expanded to assess what impact the vertical lift capability of the elevators will have on main deck cargo handling operations by considering forklift assignments and the effects of running multiple elevators simultaneously.

B. PREDICTING ELEVATOR LIFT CAPABILITY

The estimation of the vertical lift capability is accomplished by considering the times required to load, unload and move the elevator between the main deck and the various levels of the hold in the design of the simulation model. In this model, subsequently referred to as the *elevator model*, only the operation of a single elevator is considered with assumed dedicated forklifts for elevator loading and unloading. The impact of any other material handling function which might influence elevator operations is not considered in the model.

1. Defining the conditions for the simulation.

As a representation of a general case, a sample UNREP load-out of a typical requirement supporting a 90-day endurance for three small combatants (FFG's) from hold #3 is used as the basis for developing the initial estimates of the 12,000 lb elevator vertical lift capability. This data set was chosen because it reasonably approximates the typical distribution of pallets by level from hold #3 while providing a sample size sufficient to run the elevator a number of times. The sample UNREP data and required lifts are

given in Table 2. The order of the lifts is: chill items from levels 1 and 4 are broken out first followed by freeze items on levels 2 and 3.[10] An important assumption of the model is that the elevator travels between the main deck and a specified level without stopping at intermediate levels <u>even if</u> carrying a partial load.

Level	Pallet Count	Lifts
1 (Chill)	6	2 of 3 ea
2 (Freeze)	9	3 of 3 ea
3 (Freeze)	10	3 of 3 ea 1 of 1 ea
4 (Chill)	3	1 of 3 ea
Totals	28 Pallets	10 Lifts

Table 2. Sample hold #3 break-out data for small UNREP.

As a means to estimate the lift capability of the elevators over a range of conditions, three generalized categories characterizing the operating environment on the ship will be used since they will impact the operation of the forklifts while loading and unloading the elevator. The categories represent subjective assessments of the degree to which cargo handling efforts, necessary in determining the lift capability of the elevators, are hampered by the environment on the main deck and in the holds, particularly. Based on this assessment, the best estimates of the input variables given in Appendix B are adjusted to account for the presence of factors which would tend to reduce the efficiency of material handling operations. This is a common procedure for analyzing existing operations or for the synthesis of proposed systems (Apple, 1972).

Performance times for basic forklift operations derived by the USNS SAN JOSE are given in Table B-1 of Appendix B. These provide the basis for developing estimates of input variables over a range of conditions. Two important aspects of the data must be considered. First, the experiments were conducted under relatively "ideal" conditions with

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[10] The typical sequence is to breakout chill items before freeze.

the exception of maneuvering constraints imposed by the layout design of the experiment. The majority of conditions such as those listed in Appendix C that commonly reduce the efficiency of forklift operations were not present during the experiments but are representative of typical shipboard conditions. The times derived in the experiment therefore represent extremely optimistic values. Secondly, as the data in Appendix B suggests, variability is present which generally increases as the complexity of the task increases. For example, the straight away forklift speed tests demonstrate almost no variation while slightly more complicated tasks such as dropping-off or picking-up a pallet display significantly more variation. Also, during the loading and unloading experiments, where a more complex sequence tasks is required in a constrained area, the data shows the most variability. It is reasonable to expect, therefore, that less favorable conditions resulting from the presence of the other factors listed in Appendix C will result in not only increased mean operating times but increased variability as well.

A common method used to introduce variability is to apply the ranges +/- to the estimated mean values and then use a uniform or triangular distribution (Pegden, Shannon, and Sadowski, 1990). However, in the case of data obtained under ideal experimental conditions it is unlikely that the actual performance times on the ship will be less then the times obtained from the experimental time trials. Therefore, a logical alternative is to use the mean values of the data obtained during the time experiments as estimates of the lower bound (best possible performance) and the adjusted values based on the percentages as estimates of the upper bound (worst possible performance). As a suggested starting point, the three categories representing the subjective assessment of the operating environment are used. They are:

- Favorable - Expected operating times increased by 10%; Range: 0 - 20%.

- Normal - Expected operating times increased by 50%; Range:0 - 100%.

- Severe - Expected operating times increased by 100%; Range:0 - 200%.

As an example, when using the Hyster 4,000 lb (4K) forklift with its mean operating times given in Table B-1 of Appendix B as the lower bound estimates, the time ranges associated with the three environmental assessments can be determined. These times

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are given in Table 3. Cumulative times are used for loading times as a means to average the error during the loading process. However, individual times by pallet are given for unloading times since this is subsequently needed during embellishment of the elevator model when cargo delivery is considered. The elevator time delay represents the delay associated with closing the elevator door, starting the elevator, stopping the elevator, and opening the door.

Environment Allowance	Load times	Unload times	Elevator Delay
Base (Pallet Nr.)	(1) 18 (2) 36 (3) 55	(1) 17 (2) 21 (3) 22	5
Favorable 10%	(1) 18-22 (2) 36-43 (3) 55-66	(1) 17-20 (2) 21-25 (3) 22-26	5-6
Normal 50%	(1) 18-36 (2) 36-72 (3) 55-110	(1) 17-34 (2) 21-42 (3) 22-44	5-10
Severe 100%	(1) 18-54 (2) 36-108 (3) 55-165	(1) 17-51 (2) 21-63 (3) 22-66	5-15

Table 3. Input parameter time estimates by number of pallets in seconds.

An important assumption concerning loading and unloading operation time is that no trends are built into the model to indicate the relative size of the staging areas or the location of a pallet in the staging area next to the elevator. For example, it makes no difference how many pallets have been unloaded and placed in the staging area on the main deck, the expected time to unload the elevator at the beginning of the simulation is the same as at the end of the simulation even if the model should indicate a large accumulation of pallets in the staging area. In other words, there are no space constraints considered for staging operations. The same is true for loading operations. The estimates of the loading and unloading times therefore should be based on an average distance the forklift must travel between the staging area and the elevator rather than the

shortest or longest distances. For the Hyster loading and unloading times given in Appendix B the distance between the staging area and the elevator for both loading an unloading was less than ten feet.

2. Running the simulation.

At the start of the simulation (replication), the pallets (entities) are created at time zero and sent to the elevator queue in the sequence specified previously. Simulation time begins when the elevator is first dispatched from the main deck, and ends once the last pallet is placed in the staging area on the main deck. No system warm-up is provided since it is a terminating system (Law and Kelton, 1991). The starting conditions are relevant since the time of the material handling operations are relatively short. For each replication (a total of 100 replications are run) the total time required to move all of the pallets is recorded. The model was run using two assumptions concerning the underlying distributions of the input data. The first assumption is that the data is uniformly distributed across the range defined by the environmental assessment. This distribution is not based on any empirical or theoretical justification other than an assumption that any outcome along the range is equally likely (Pegden, Shannon, and Sadowski; 1990). Secondly, the triangular distribution is used only as a matter of comparison.

3. Results of the elevator model simulation.

The output of the simulation is summarized in Table 4. The mean times represent the estimates of the total time required to move all 28 pallets from the various levels of the hold to the main deck staging area under the three specified operating environments. Range reflects dispersal in the data by giving the smallest and largest observed times while 95% confidence intervals are the intervals that have a 95% probability of containing the true population mean. The increases in the mean times and the ranges correspond directly with reduced efficiency and increased variability of the material handling functions comprising the components of the elevator system model. Despite the variability given to the input variables, the output times display remarkably little variation. The extreme times fall within a few minutes of the mean even under severe conditions. This suggests that given accurate assessments of the operating environment the total time required to move a specified number of pallets can be predicted with very good accuracy. In an additional run of the model under normal conditions, replacing the uniform distribution with

the triangular distribution further reduced the range in the data by 2 minutes and resulted in the same mean time. This indicates that by selecting underlying distributions of the input data which are less variable, if justified, even more precise estimates of the elevator output performance can be made.

Environmental Assessment	Range (Lower - Upper)	95% Confidence interval	Mean
Favorable - 20%	27.1 - 28.0	27.6 - 27.6	27.6
Normal - 50%	32.6 - 37.1	35.0 - 35.4	35.2
Severe - 100%	39.3 - 48.4	44.2 - 44.9	44.6

Table 4. Total times required to move all pallets from the hold staging area to the staging area on the main deck, in minutes.

Since the output times are random variables they can also be described by probability distributions. According to our analysis, the distribution for the operating times of the elevator operating times under favorable and normal conditions did not fit meaningful distributions because of the small range in the data. The Chi-square test to evaluate the hypothesis of a Normal distribution for elevator operations under severe conditions resulted in a p-value of 0.441. From this a conclusion that the Normal distribution is an acceptable distribution for the elevator operating times under severe conditions is significant at a level of alpha equal to 0.1 or even higher. The histogram of the output data under severe conditions is shown in Figure 4. The "blocks" in the "curves" demonstrate the relative frequency of the observations over the range of the data. Fitting theoretical probability distributions is accomplished using the statistical package included with the SIMAN program. The smooth curves in Figure 4 correspond to the theoretical distributions.

Severe Operating Environment

REAL data	Data pts = 100	Intervals = 10	Range: 40 to 50
Mean = 44.6	StdDev = 1.76	Min = 40.3	Max = 49.4
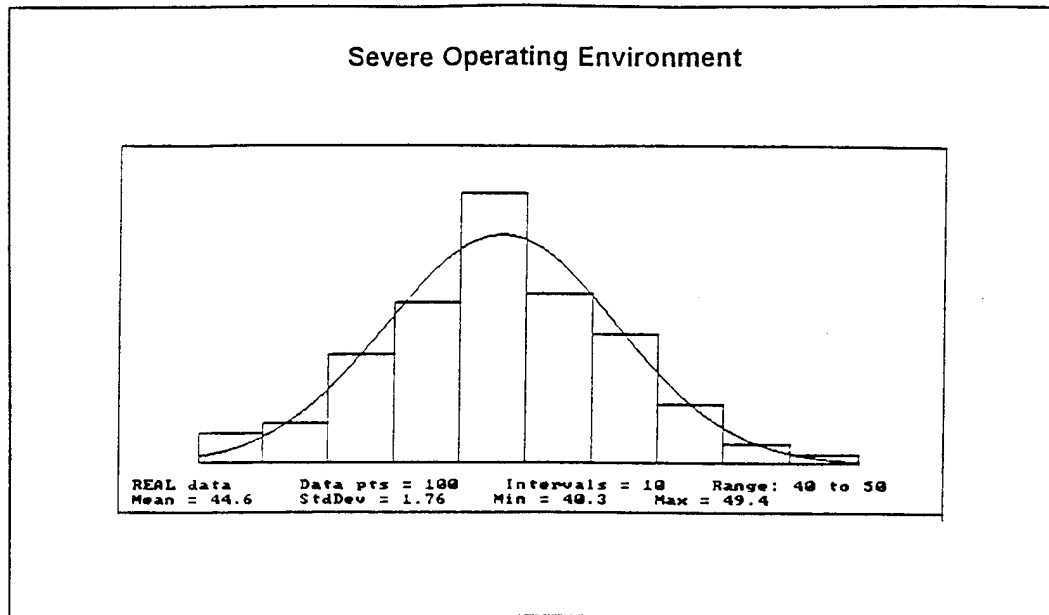
Figure 4. The results of distribution fitting for simulated elevator operating times for sample UNREP.

a. Comparing other scenarios.

In Figure 5 the results of running the model assuming a normal environment with 24 pallets equally distributed among the levels is shown. This particular number and distribution of pallets was chosen because 6 pallets per level (assuming four levels) allows for dividing the number evenly among the levels at 1, 2 or 3 pallets per lift without ever creating stragglers that must be picked up with a separate run of the elevator.[11] The results with 3 pallets per lift, under normal conditions average almost exactly the same time per pallet (1.25 minutes) as the previous example (with 28 pallets total). Reducing the number of pallets carried per lift increases the total cycle time but not by as much as one might expect. Dropping from three to two pallets per lift only increases the total time by 9.3% while carrying a single pallet per lift yields an increase of just 40% over the 3 pallets per lift results. This indicates that occasionally carrying fewer than the maximum number of pallets per lift will not significantly reduce the efficiency of the lift.

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[11] The intent here is to isolate the net effect of carrying fewer pallets per lift rather than causing additional runs of the elevator to pick up a pallet that was left.

To investigate the impact of different distributions of pallets among the levels the model was run again under normal conditions first with 28 pallets split between the upper two levels and then split between the lower two levels of the hold. With the pallets located only on the upper two levels the mean time to complete the task was 30.8 minutes which is slightly better than the 32.5 minutes using the sample UNREP data where the pallets were spread relatively equally among the levels. With all of the pallets on the bottom levels the mean time was increased to 36.3 minutes. On a per pallet basis the difference between the distributions of pallets is rather small at about 12 seconds per pallet between the extremes.
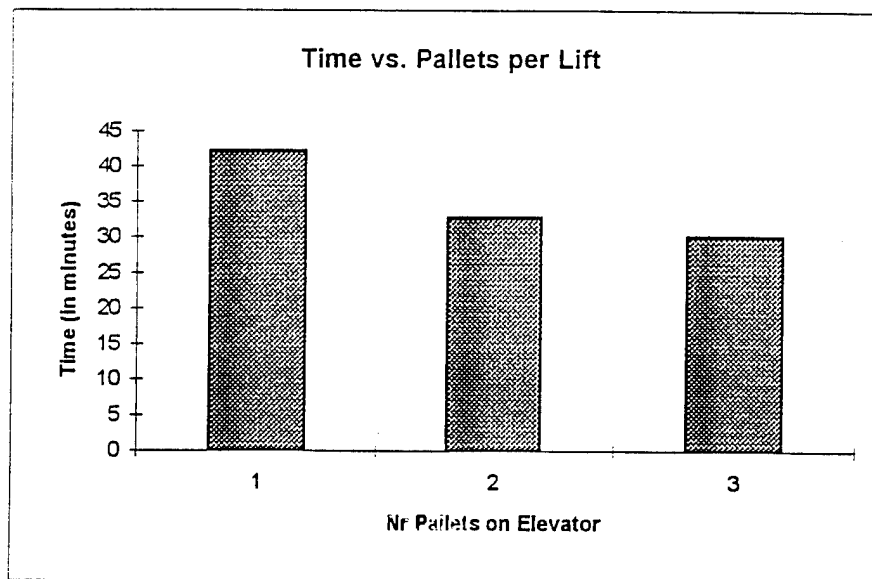
Figure 5. Cargo movement times when varying the number of pallets per lift.

4. Elevator lift capability planning estimates.

The results of the simulation support that cargo handlers can expect to average between one pallet per minute under favorable conditions to just over a minute and a half per pallet under severe operating conditions. Additional variation will result if the elevators operate with fewer than the three pallets per lift or if the distribution of pallets is not evenly

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dispersed among the levels of the hold. These estimates represent reasonable approximations given the assumptions of dedicated forklifts to load and unload the elevator and the range of operating environments described.

C. MAIN DECK CARGO DELIVERY OPERATIONS

Operating multiple elevators simultaneously while at the same time delivering cargo complicates decisions concerning main deck forklift assignments. The goal of the following analysis is to use the simulation model to evaluate the effects of alternative assignments of forklifts when delivering cargo to the after cargo staging area from holds #3 and #4. This will be accomplished in a three step-process. First, the operations of hold #3 and hold #4 will each be considered independently and then the combined effect of operating both of these holds simultaneously will be addressed to determine the overall effect on material handling functions for the ship.

1. Defining the conditions for the simulation.

In this model, the elevator model is expanded to include cargo delivery operations on the main deck. Table 5 gives estimates for forklift speeds (the Hyster 4K speed is used as the base speed) and maneuvering times while dropping-off or picking-up a pallet with a 180 degree change of direction. These times are used to describe delivery forklift movements on the main deck. Turn-around times shown are applied at both the elevator staging area and the after cargo staging area as the main deck delivery forklifts maneuver prior to heading up or down the aisle running down the starboard side of the ship. Estimates for both of these variables were obtained from Appendix B, Tables B-1 and B-2.

As with the elevator estimates, these times are specified over a range representing the three general assessments of the operating environments impacting cargo handling efforts on the main deck. For the forklift speeds, the environmental allowance adjustment reduces the lower bound estimate of the speed to 80% for fast conditions, 60% for medium conditions and finally a range of 40% to 60% is used for slow conditions. The expected values expressed as a percentage are given in the allowance column. In the case of forklift turn-around time, the estimate of .27 minutes was obtained from standardized data given in Appendix B, Table B-2 and appears to be overly pessimistic. This opinion is based conversations with Mr. Jim Lurch at the Hyster Corporation Training Division in Portland Oregon who suggested that a more reasonable estimate for ideal

conditions is 10 seconds or .17 minutes (when operating in a warehouse). As a compromise, .27 minutes was selected as the base for both drop-off and pick-up times, recognizing that aboard ship the forklift would probably not perform as well as Mr. Lurch's estimate. However, when adjusting for the operating environment the time was not adjusted beyond .54 minutes even for the severe conditions.

There are several important assumptions that were made to make the problem tractable for this model. First, elevator operations continue without regard to main deck cargo delivery functions. The elevator operates until no more pallets are left in the hold and the sequence of lifts given at the start of the simulation is not altered. Forklifts assigned to delivering cargo between the staging areas at the elevator and after cargo do

Environment Allowance	Forklift Speed	Forklift turn-around
Base	430 ft/min	.27 min
Fast (90% of max)	344-430	.27-.32
Medium (80% of max)	258-430	.27-.54
Slow (50% of Max)	172-258	.27-.54

Table 5. Cargo delivery parameter estimates.

not unload the elevator and will remain idle wherever they are located if there are no pallets to be moved. If the delivery forklifts are unable to keep up with the elevator no limit is placed on the backlog at the staging areas next to the elevators nor does it slow the unloading operation. Second, the narrow aisle is incorporated in the model and allows only a single forklift in the aisle at a time. The priority regardless of the direction of the forklift is first-come-first-serve. The logic in the model also does not distinguish between the direction of travel of the forklifts so if the aisle is already occupied an arriving forklift must wait even if it is heading in the same direction.[12] Thirdly, while no

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[12] The result of this will be to overstate the time lost due to the narrow aisle. This loss is partially offset, however, because it has the effect of staggering the arrivals of forklifts to after cargo and therefore avoids some congestion when attempting to unload pallets. This program error is therefore mitigated to some degree.

competition between forklifts in after cargo area (this area is assumed to be sufficiently large to have multiple forklifts operating simultaneously) is included in the model, the staging area at the elevator is much smaller and therefore only a single forklift is permitted in this staging area at a time. The delivery forklifts and the forklift unloading the elevator must share this resource on a first-come-first-serve basis. For the delivery forklifts, they control this space for the period equal to the pallet pick-up and turn-around time given in Table 5. For the elevator unloading forklift the period of control is 20% of the time needed to unload the elevator (the other 80% is assumed to be spent maneuvering in the elevator or travelling between the elevator and the staging area. Finally, while operating in the narrow aisle the speed of the delivery forklifts is reduced by an additional 20% beyond the reduction based on the environmental assessment. This is intended to reflect the added care that must be taken when negotiating the narrow aisle where cross traffic visibility is obscured while at the same time avoiding the walls on either side especially when carrying a load or when operating at night.

2. Hold #3 elevator and cargo delivery operations.

An important aspect of cargo movements on the main deck is the delivery of refrigerated stores from hold #3 to after cargo on the main deck. The need to keep these stores cold requires that they be kept in the hold until just prior to the beginning of the UNREP. Cargo handling involving hold #3 consequently is always a critical operation. The changes arising from the improved vertical lift capability of the elevators and the narrow aisle created by the installation of the new elevators for holds #4 and #5 results in an undetermined impact on cargo delivery operations.

The analysis of cargo movement from hold #3 will be based on the same sample UNREP data used in the elevator model. At the start of the simulation the elevator is located at the main deck with the assigned delivery forklifts standing by at the staging area. Delivery forklifts transit directly from hold #3 to after cargo along the starboard passageway dropping pallets in a staging area located just in front of the flight deck elevators.

a. Running the simulation.

At the start of a simulation run, pallets are created at time zero and sent to the elevator queue. The simulation clock starts when the elevator is first dispatched from the main deck and ends when the final pallet is placed in the staging area in after cargo. The model is run over all ranges of conditions previously defined for both the elevator operations and the forklift operations while considering various assignments of forklifts.

b. Results

Details of the simulation results are provided in Appendix F. The total time of the operation, referred to as the "UNREP time", the percentage utilization of the delivery forklifts and the average size of the backlog at the elevator staging area on the main deck over time are given in the table. In Figure 6, the graphs depict the results illustrating the impact of assigning one, two or three forklifts to cargo delivery operations. The range of times to move all 28 pallets from the hold to after cargo is rather broad spanning between a high of 98.5 minutes to a low of 30.6 minutes. The most compelling information apparent in the data is that the elevator is capable of delivering cargo to the main deck faster than a single forklift can move it to after cargo. This is illustrated by the high percent utilization of the forklift which is 96% even when the elevator is delivering cargo at its slowest rate. By adding a second delivery forklift the total UNREP time is reduced across all the specified operating environments by nearly 50% in many instances. As expected, increases in the elevator lift rate, or slower forklift speeds will tend to increase the benefit of adding the second forklift. Adding a third forklift, however, provides only a marginal reduction in time with the most benefit occurring when the elevator is operating at the highest efficiency and the forklifts are moving at their slowest speeds.

Another important aspect of adding a second forklift is that it reduces the congestion at the main deck elevator staging area. For example, Figure 7 shows a scatter diagram containing data points from 5 replications (each dot represents the number of pallets in the staging area at the point in time shown on the horizontal axis during the operation of the elevator) when normal operating conditions are assumed. It

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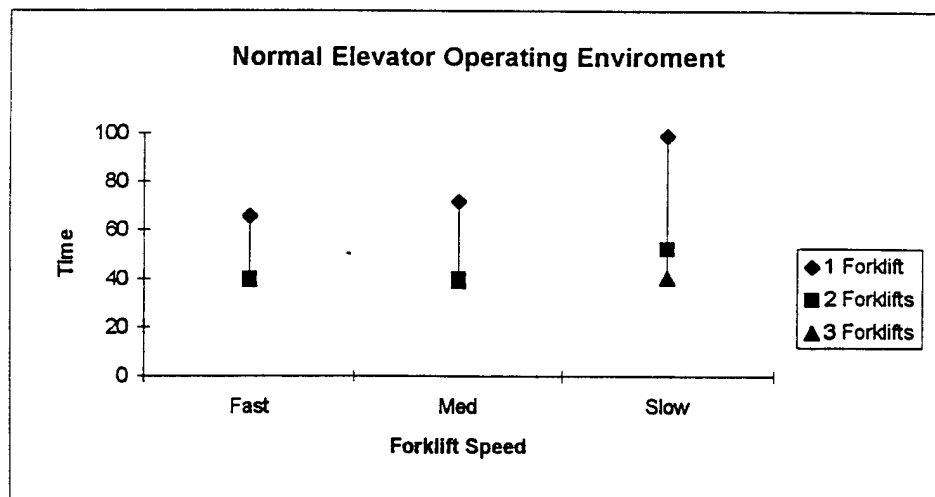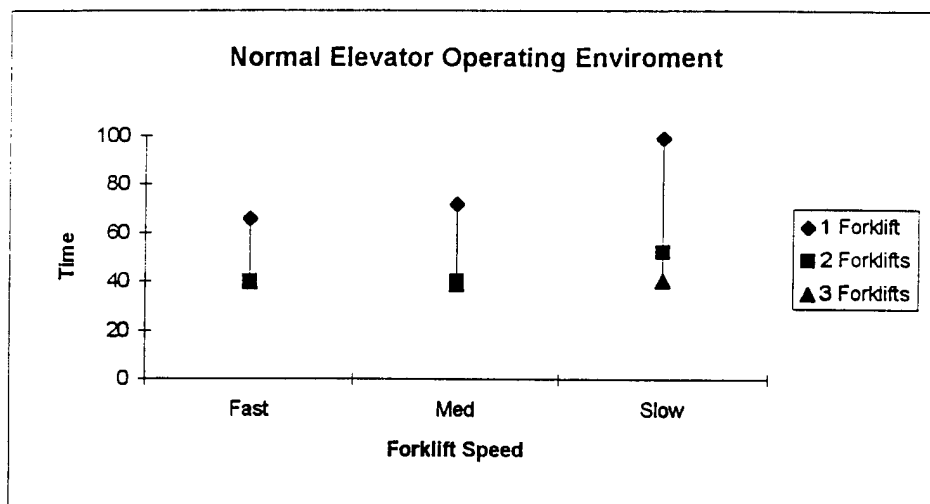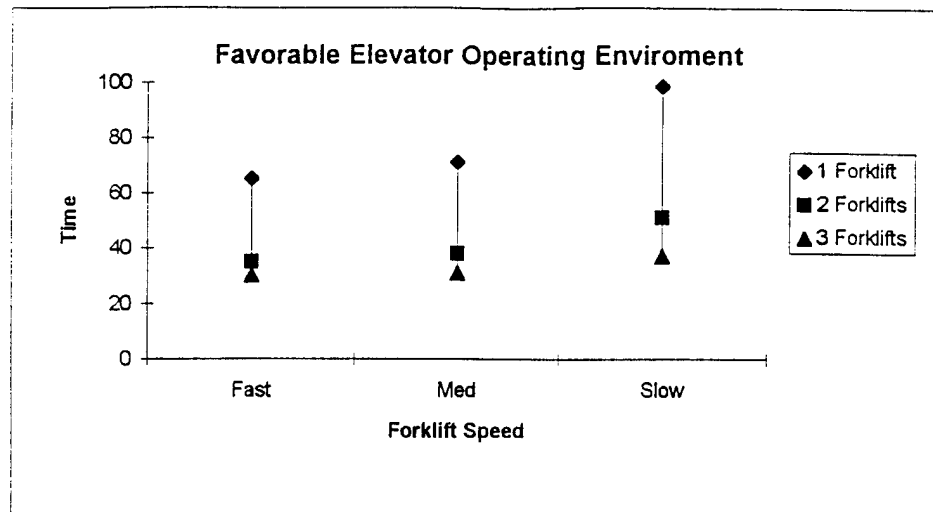
Figure 6. Results of forklift assignments for hold #3.

illustrates that the number of pallets steadily increases over the course of time at the elevator staging area when a single forklift is assigned to cargo delivery operations. The peak in the data represents the maximum number of pallets backlogged at the staging area and marks the point when the elevator has completed moving the pallets up from the hold. Operating with two delivery forklifts almost completely eliminates any backlog at the staging area as seen in the second graph in the figure. Here the maximum number of pallets accumulating in the staging area at one time is only two. In practice the ship might find that the added benefit of avoiding a large accumulation of pallets at the elevator staging area may provide additional time savings by avoiding unwanted congestion.
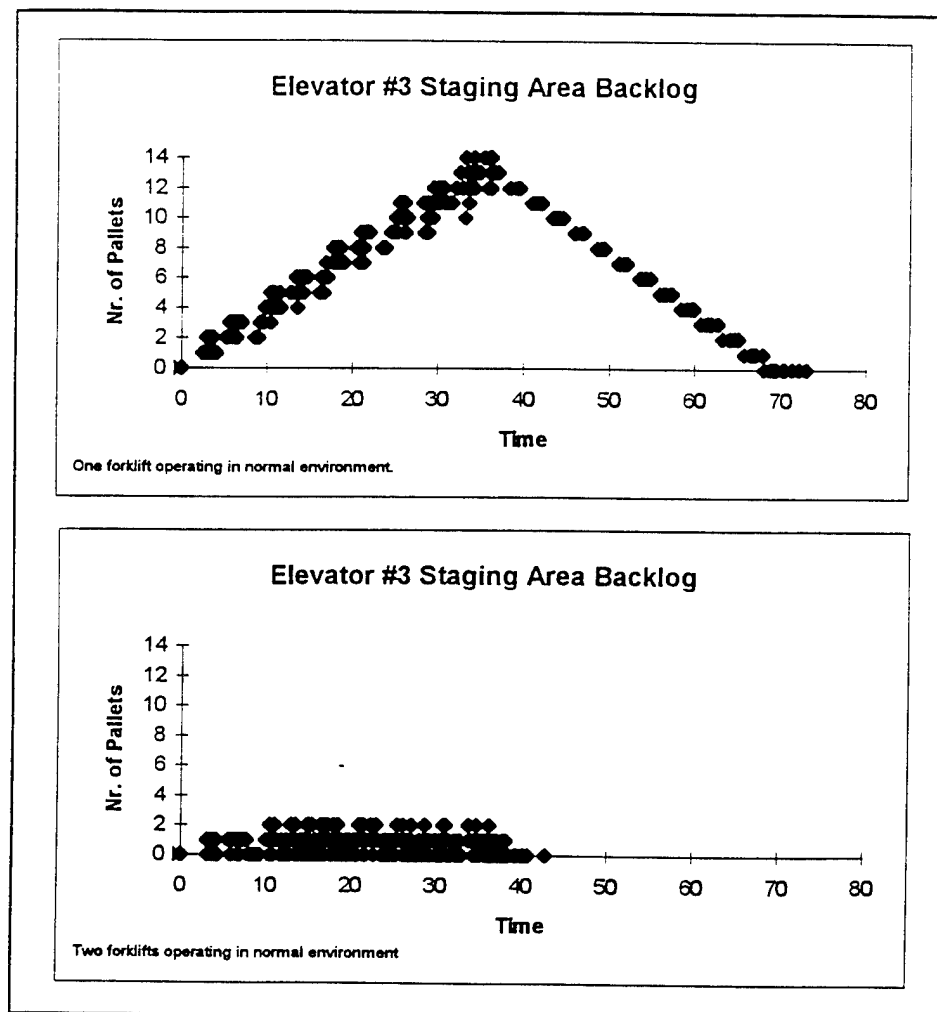
Figure 7. Elevator #3 backlog with one and two forklifts assigned.

3. Hold #4 elevator and cargo delivery operations.

Hold #4 is located just forward of the after cargo staging and, as a result, cargo intended to be sent to after cargo for staging has a substantially shorter distance to travel compared to hold #3 cargo. Because the elevator is located adjacent to the narrow aisle area the delivery forklifts operating from hold #4 enter directly into the narrow aisle before heading to after cargo. In the following analysis only the operations of hold #4 are considered. A sample UNREP load-out representing a typical requirement supporting a 90-day endurance for three small combatants (FFG's) is used as an example for hold #4. This data set was also chosen as a reasonably approximation of the typical distribution of pallets by level from hold #4. The sample UNREP data for hold #4 is given in Table 6. The order of the lifts is by level beginning with the first level.

Level	Pallet Count	Lifts
1 (Dry provisions)	12	4 of 3 ea
2 (Dry Provisions)	15	5 of 3 ea
3 (Clothing, Ship's Store)	10	3 of 3 ea 1 of 1 ea
4 (Ship's Store)	3	1 of 3 ea
Totals	40 Pallets	14 Lifts

Table 6. Sample hold #4 break-out data for small UNREP.

a. Running the simulation.

Running the simulation proceeds in the same manner as given for hold #3. The simulation clock starts when the elevator is first dispatched from the main deck and ends when the last pallet is placed in the staging area in after cargo. The model is run over all ranges of conditions previously defined. Statistics gathered include forklift utilization, staging area queues, and the total time required to move the cargo.

b. Results

Details of the results of the simulation experiments for hold #4 are also provided in Appendix F. Since there are 12 more pallets to move for this hold then for hold #3 the data is not directly comparable to that associated with hold #3. In Figure 8 the results of using one or two forklifts can be seen over the full range of conditions. For hold #4, as we might expect, adding a second forklift for cargo delivery provides the most benefit when the elevator is operating under favorable conditions and the forklifts are operating at their slowest rate. The impact of the shorter distance that must be covered by the delivery forklifts is also evident in the scatter diagram shown in Figure 9 (data points from five replications are shown) where the backlog builds much slower then that of hold #3 and does not reach the same maximum level because it takes less time for the delivery forklift to transit between the hold #4 staging area and after cargo. In the second graph in the figure, the assignment of two forklifts results in a maximum of only one pallet waiting at the elevator staging area indicating that two forklifts are completely capable of keeping up with the elevator. The value of adding a second forklift for hold #4 is significantly less beneficial compared to hold #3 in all scenarios. Therefore, the impact of using 3 forklifts was not considered in the simulation runs.

4. Cargo delivery with simultaneously operating elevators.

The key consideration when operating several elevators simultaneously is the potential for traffic congestion as the delivery forklifts maneuver in crowded conditions while dodging people, other forklifts, and whatever other objects might impede traffic flow. For holds #3 and #4 which, when combined, account for the majority of cargo to be moved for most UNREPs, concern about the narrow aisle seems more than justified since they are both forward of the narrow aisle yet normally the cargo they contain must be moved to after cargo via this aisle for transfer by VERTREP.

The narrow aisle was expanded ten feet in either direction in the model to account for the "squeeze zone" as forklifts prepare to enter the aisle. For hold #4 this ten-foot section occurs in the area where forklifts exiting from the staging area at the elevator merge into the traffic in the starboard aisle. Therefore, the space allotted for the squeeze zone also includes the merge point for forklifts entering from the hold #4 staging area.
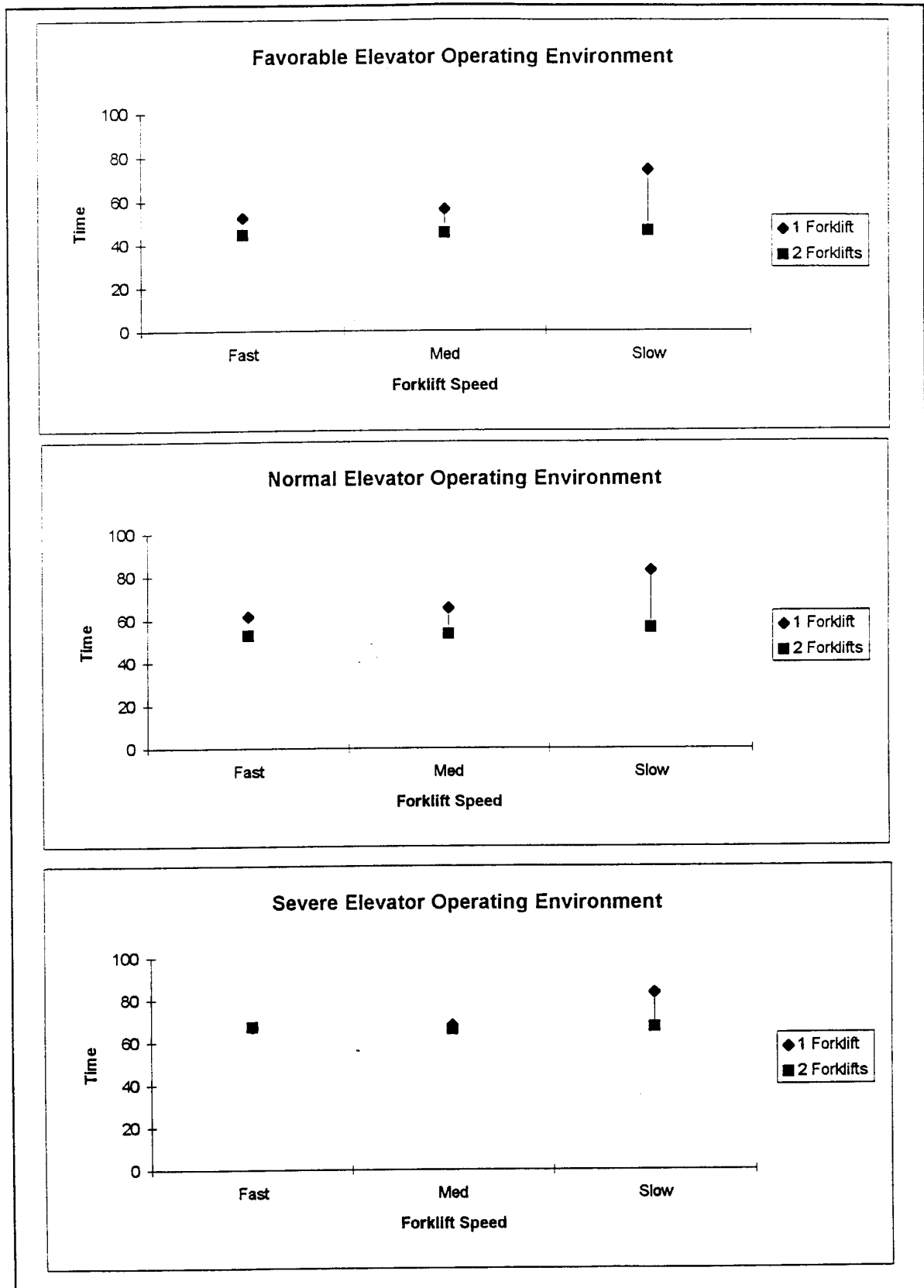
Figure 8. Results of forklift assignments for hold #4.
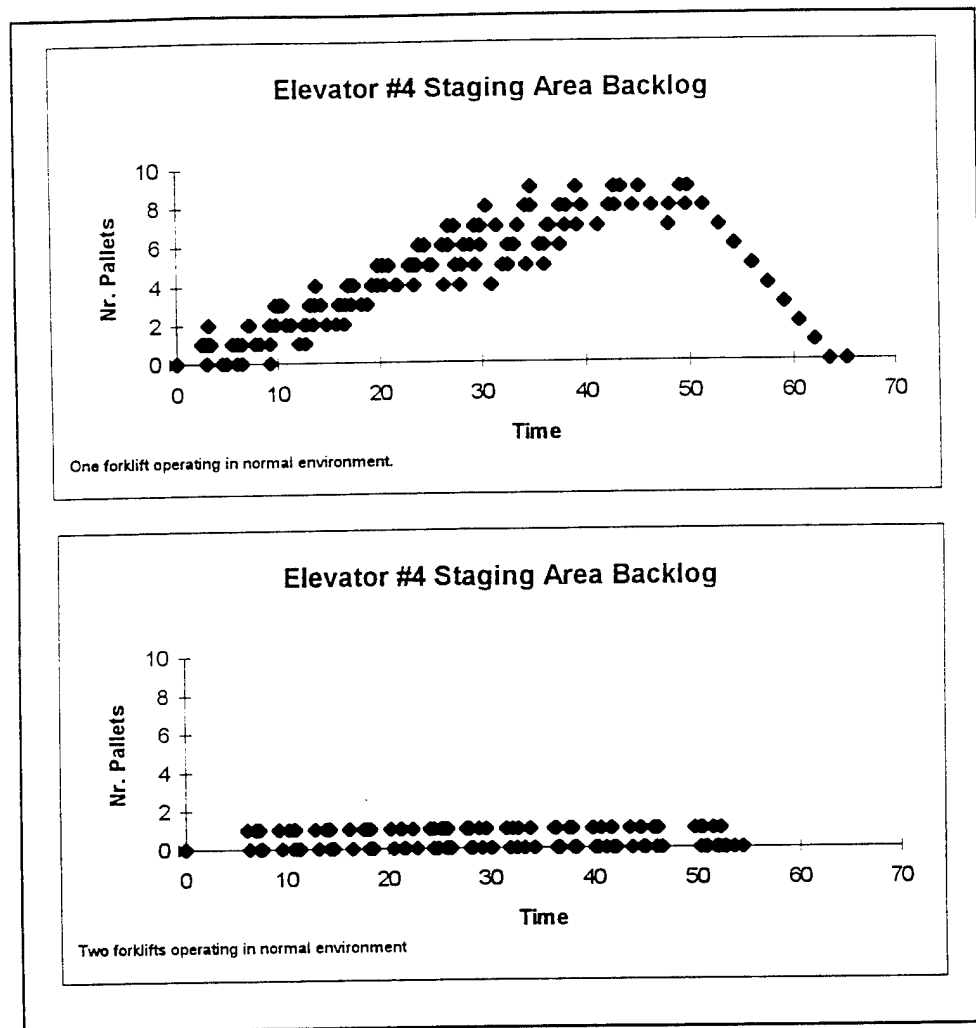
Figure 9. Elevator #4 backlog with one and two forklifts assigned.

a. Measuring the impact of the narrow aisle.

By comparing the results of running the simulation first with single access permitted to the narrow aisle and then eliminating the restriction the impact of the narrow aisle is isolated. The net difference that can be expected due to the delays introduced as forklifts wait their turn for this resource are given in Appendix G and is illustrated in Figure 10. The times represent the difference in the total time to move all pallets from both holds caused by the narrow aisle delaying forklift movements. One limitation of this approach is that it only accounts for the increase in operating time not the total time spent waiting for access to the narrow aisle.

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In Appendix G and Figure 10 the net time loss is illustrated as an example when the elevators are operating in a normal environment using the sample UNREP data presented previously. Under normal conditions the longest delay occurs when a single forklift is assigned to cargo delivery for each hold at 3.6 minutes. The congestion also causes a slight increase in the variability of the estimated completion times as indicated in the data summary in Appendix G. The worst case occurs when two forklifts are serving hold #3 and one forklift is serving hold #4. The net increase in the mean UNREP time is 5.1 minutes when the elevators are operating under favorable conditions and the forklifts are moving at their slowest speeds.
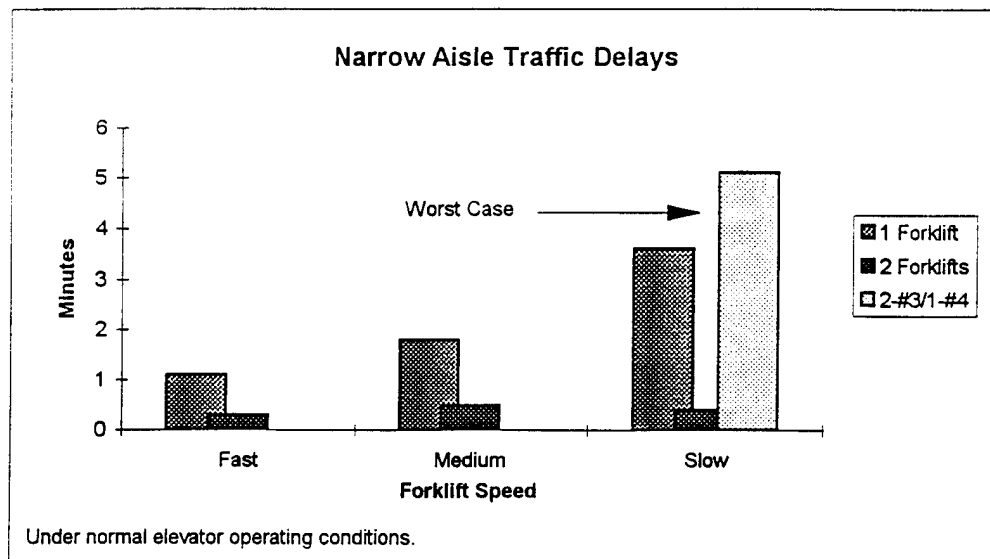
Figure 10. Net time loss due to narrow aisle causing traffic delays.

From this, the conclusion is that the narrow aisle will have little effect on the total time needed to move cargo back to after cargo even with the elevators at holds #3 and #4 are operating at the same time. The primary reason for this is that when only one forklift is assigned per hold there isn't much opportunity for congestion at the narrow aisle. But, by adding additional forklifts the excess capacity relative to the elevator capabilities allows for absorbing the efficiency lost when must forklifts wait on either end of the narrow aisle without increasing the total time to complete the cargo movement.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY.

In this thesis we present a simulation model of cargo handling to examine the operating characteristics of the upgraded cargo handling system being installed on the USNS SAN JOSE. The uncertainty associated with conducting cargo handling operations with substantially upgraded equipment and almost an entirely new crew, as a consequence of the transfer of the ship to the MSC, prompted the interest in this research. The goal was to develop a decision support tool using simulation methods in order to assist cargo planning efforts.

In Chapter II a description of the existing cargo handling system provided the background of the design concept of MARS Class ships and explained how cargo handling operations were conducted using the system of package conveyors originally installed in the ship's holds. Meeting mission requirements with the older conveyor systems depended heavily on large crew sizes and the pre-staging of cargo because of the labor intensive nature of conveyor operations. The major conclusions of the key studies conducted by the Naval Ship Weapons Systems Engineering Station at Port Hueneme which supported the transfer of the MARS Class ships to the MSC were also presented. Finally, the details of the modernization of the elevators and conveyors for the USNS SAN JOSE are presented. The major improvement resulting from the upgrade of the vertical cargo handling system is the addition of three 12,000 lb capacity elevators capable of handling three pallets at a time.

Chapter III discussed the advantages of using simulation modeling in material handling problems and described the key components of the model presented in this thesis. The ability to provide a systems view of the operation of a complex system is the reason simulation modeling was chosen to predict the performance characteristics of the improved cargo handling system on the USNS SAN JOSE.

In Chapter IV, the simulation model is demonstrated in two scenarios. In the first, planning estimates are determined for the vertical lift capability of the newly installed 12,000 lb capacity elevators using sample UNREP data. In the second scenario, the scope of the model is expanded to assess what impact the elevators will have on main deck cargo delivery operations when operating the elevators for holds #3 and #4.

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B. CONCLUSIONS

1. Planning estimates for elevator operations.

The simulated operation of the 12,000 lb cargo elevators over a range of conditions is used to estimate the vertical lift capability of the elevators. The conditions specified are based on subjective assessments of the effects of various operating environments on cargo handling efforts related to elevator operations. Estimated times of basic material handling functions derived from simple time study experiments and standardized time study data are then adjusted to reflect these operating conditions. These adjusted times are used in the model to define the input variables for loading, unloading and operating the elevator.

The results of the simulated operation of the elevators suggest a general planning estimate of between one and one and a half minutes per pallet is an appropriate approximation. This estimate assumes that staging areas are located very close to the elevator and that accessibility to the pallets does not change over the course of time the elevator is in operation. Varying the distribution of pallets among the levels or running the elevator with occasional partial loads will have a relatively minor impact on this planning estimate.

2. Main deck cargo handling operations.

Forklift delivery operations from the main deck elevator staging areas at holds #3 and #4 to the after cargo staging area under the ship's flight deck was also simulated over a range of conditions for both for the elevators and the forklifts. In general, the results of the simulation indicate that the vertical lift capability of the 12,000 lb elevators exceeds the capacity of a single cargo delivery forklift operating between the elevator staging area and the after cargo staging area. By adding a second cargo delivery forklift per hold a significant reduction in the material handling time can be achieved under almost all operating conditions. Adding a third forklift, however, provides little additional benefit over most expected operating conditions.

For hold #3, with a single forklift assigned to cargo delivery, the efficiency of the elevator is largely immaterial with respect to the movement of cargo to the after cargo staging area over the ranges specified in this research. In contrast, hold #4, which is 160 feet closer to the after cargo staging area, is more sensitive to changes in the vertical lift

capability of the elevator and only benefits from adding a second delivery forklift when the elevator is operating near its maximum capacity and is correspondingly less affected by increases in forklift operating speeds or by adding a second delivery forklift. For either hold, but particularly hold #4, adding a second delivery forklift results in excess capacity in most operating environments as measured by percent utilization over the time.

The impact that the narrow aisle along the aft portion of the main deck aisle will have on cargo delivery operations to the after cargo area is relatively minor when considered in terms of the net added delay to the total material handling time. Generally, assigning a single delivery forklift to holds #3 and #4 does not provide sufficient opportunity for traffic congestion at the narrow aisle while assigning two forklifts per hold creates enough excess delivery capability relative to the elevator lift capability that time lost due to congestion at the narrow aisle is of minor consequence. In the worst case, a five minute delay was incurred for a sample UNREP of 28 pallets from hold #3 and 40 pallets from hold #4 when moving cargo from the elevator staging areas to after cargo.

3. The use of simulation modeling.

Simulation modeling provides a practical and effective quantitative method to aid in the analysis of cargo handling operations. Its primary advantage is that it is capable of considering the complex interaction of the many factors impacting cargo handling functions while providing a system's perspective to problem analysis. By looking at the overall output of the system rather than its components, a more efficient overall method can determined which will benefit cargo handling efforts. On the USNS SAN JOSE where the manning levels have been sharply reduced this may be particular beneficial.

As true with all models, simulation models are highly dependent on the quality of the input data and the assumptions of the model design and therefore care must be taken analyzing the output data. In addition, since simulation only provides results based on inputs it still requires the expert judgement of skilled cargo handling personnel to evaluate the results and suggest alternatives to be considered. It is a tool that should be used to supplement the decision process rather than replace it.

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C. RECOMMENDATIONS FOR FURTHER STUDIES.

In this thesis we concentrated only on cargo delivery for holds #3 and #4 since they are the most critical aspects of the cargo handling operations at the time of an UNREP. However, the model was written in a modular form so that the user can expand this model to assess the impact of other cargo handling functions. By including cargo transfer at the replenishment stations and delivery of cargo to the flight deck a more comprehensive and integrated analysis of cargo handling can be accomplished. Expanding the model will be beneficial since it will aid scheduling and sequencing decisions for more complicated scenarios than those presented.

Secondly, only limited use was made of the statistics gathering capability of the SIMAN program. Considerable additional statistical information is obtainable from the model concerning resource utilization, cargo flow times, and staging area operations that may be useful in improving cargo handling planning.

APPENDIX A. LIST OF ABBREVIATIONS AND ACRONYMS

CLF	Combat Logistics Force
CNA	Center for Naval Analysis
CNO	Chief of Naval Operations
CONREP	Connected Replenishment
FFG	Guided Missile Frigate
MILDET	Military Department
MSC	Military Sealift Command
NAVOSH	Naval Occupational Safety and Health
NWP	Naval Warfare Publication
NASSCO	National Steel and Shipbuilding Company
RAS	Replenishment at Sea
REFTRA	Refresher Training
ROC	Required Operational Capabilities
SQT	Ship Qualification Trials
UNREP	Underway Replenishment
URG	Underway Replenishment Group
USNS	United States Naval Ship
VERTREP	Vertical Replenishment

APPENDIX B. PARAMETER ESTIMATES

A. SOURCE OF PARAMETER ESTIMATES

In this appendix estimated times for basic forklift and elevator operations are provided. The data for the elevator time estimate was obtained from an initial test run of the installed 12,000 lb elevator in hold #5 on board the USNS SAN JOSE. Forklift operating time estimates are based on observed data collected from a series of experiments conducted in a warehouse by USNS SAN JOSE MILDET personnel using the ship's forklifts and a simple mock-up of the elevator dimensions and typical staging methods. Standardized data is also used to estimate basic forklift operations as a means of validating the time study results and supplying data not otherwise obtained. The time estimates in this appendix are used as suggested parameters estimates for input variables in the experimental frame of the simulation model.

B. FORKLIFT OPERATIONS

1. Observed time estimates.

The forklift time experiments were conducted under favorable conditions compared to shipboard environments where unplanned interruptions or delays often occur as a result of causes such as those listed in Appendix C. These factors, other than the physical dimension restrictions imposed by the layout design, were not present during the experiments. The resulting times obtained therefore represent the best achievable performance rather than expected or average performance times. The results of the time studies are given in Table B-1.

a. Forklift speed tests.

In the forklift speed tests the driver attempted to travel at the rate normally achieved when operating as sea but without considering obstacles or other delays.

b. Elevator loading times.

The loading times were determined by recording the time required to move the pallets from a staging area immediately adjacent to the elevator (approximately 6-10 feet to the side) with the front of the pallet at a 90-degree angle to the elevator. The loading operation consists of picking up the pallet, backing to line-up with the elevator, making a single 90-degree turn, and then placing the pallet in the elevator. Time begins when the forklift approaches the first pallet (from about one foot away) in the staging area and ends when it backs out just clear of the elevator door. Individual time are given for each pallet of a three-pallet load.

c. Elevator unloading times.

Unloading times were based on a forklift entering into the elevator, picking up a pallet, backing and turning 90 degrees to the side, then driving forward to place the pallet in the staging area which was less than ten feet off to the side of the elevator. Time begins as the forklift approaches the elevator opening and ends when the last pallet is dropped in the staging area. Individual time are given for each pallet of a three-pallet load.

Forklift Speed Test*

Forklift	1	2	Trials 3	4	5	Average
Pettibone	17	17	17	17	17	17
Hyster 4K	14	14	14	14	14	14
Hyster 6K	13	14	13	14	14	13.5

* Based on time to travel 100ft with a running start and finish (in seconds).

Forklift Pallet Loading/unloading Times*

Pallet pick-up

Forklift	1	2	3	4	Trials 5	6	7	8	9	10	Average
Pettibone	5	5	5	5	6	5	5	6	5	5	5.2
Hyster 4K	6	7	5	4	4	5	4	5	4	4	4.8

Pallet drop off

Forklift	1	2	3	4	5	6	7	8	9	10	Average
Pettibone	8	6	5	6	6	6	6	5	5	6	5.9
Hyster 4K	7	6	6	6	5	6	5	6	5	6	5.8

* Based on time required pick-up and drop-off a pallet from a running start (in seconds).

Elevator Loading Times - Pettibone Truck

Trial	1st Pallet	2nd Pallet	3rd Pallet	Total Time
1	17.0	19.0	35.0	71.0
2	20.0	20.0	25.0	65.0
3	18.0	20.0	25.0	63.0
4	17.0	21.0	25.0	63.0
5	18.0	22.0	25.0	65.0
6	18.0	22.0	24.0	64.0
7	17.0	23.0	24.0	64.0
8	18.0	22.0	28.0	68.0
Average	17.9	21.1	26.1	65.1
Variance	0.98	1.84	13.27	6.70

Elevator Loading Times - Hyster Forktruck

Trial	1st Pallet	2nd Pallet	3rd Pallet	Total Time
1	18.0	22.0	25.0	65.0
2	19.0	20.0	18.0	57.0
3	19.0	18.0	19.0	56.0
4	16.0	16.0	16.0	48.0
5	18.0	17.0	18.0	53.0
6	17.0	19.0	17.0	53.0
7	16.0	18.0	20.0	54.0
8	19.0	17.0	18.0	54.0
Average	17.8	18.4	18.9	55.0
Variance	1.64	3.70	7.55	23.43

Elevator Unloading Times - Pettibone Truck

Trial	1st Pallet	2nd Pallet	3rd Pallet	Total Time
1	18.0	24.0	26.0	68.0
2	17.0	22.0	25.0	64.0
3	17.0	23.0	23.0	63.0
4	18.0	22.0	25.0	65.0
5	17.0	23.0	24.0	64.0
6	18.0	23.0	25.0	66.0
7	19.0	22.0	25.0	66.0
8	18.0	23.0	24.0	65.0
Average	17.8	22.8	24.6	65.1
Variance	0.50	0.50	0.84	2.41

Elevator Unloading Times - Hyster Forktruck

Trial	1st Pallet	2nd Pallet	3rd Pallet	Total Time
1	19.0	18.0	24.0	61.0
2	15.0	23.0	23.0	61.0
3	14.0	19.0	22.0	55.0
4	17.0	22.0	21.0	60.0
5	16.0	21.0	22.0	59.0
6	18.0	23.0	21.0	62.0
7	19.0	22.0	23.0	64.0
8	20.0	21.0	22.0	63.0
Average	17.3	21.1	22.3	60.6
Variance	4.50	3.27	1.07	7.70

Times are in seconds.

Table B-1. Observed data based on forklift time experiments.

2. Standardized data time estimates.

The standardized data used to develop the time estimates in Table B-2 is based on data gathered by the Yale & Towne Manufacturing Company (Apple, 1972). Time standards are given for basic forklift motions which must be tabulated and adjusted for environmental operating conditions listed in Appendix C. Allowances are required since the standardized times do not directly consider human factors and environmental conditions that affect forklift operations. The procedure of using adjusted standardized data is a common procedure for analyzing existing operations or for the synthesis of proposed systems (Apple, 1972). Since the standardized data is specific for a particular Yale forklift it is only usable as a rough estimate.

Pallet Drop-off

Activity	Distance/ occurrence	Allowance			Factor *	Computed times (minutes)		
		a	m	b		a	m	b
Stop	1	100%	75%	50%	0.0330	0.0330	0.0248	0.0165
Run-out	1	100%	100%	100%	0.0650	0.0650	0.0650	0.0650
Accelerate	1	100%	75%	50%	0.0300	0.0300	0.0225	0.0150
Back and stop	1	100%	150%	200%	0.0600	0.0600	0.0900	0.1200
Accelerate	1	100%	75%	50%	0.0300	0.0300	0.0225	0.0150
Left Forward	1	100%	150%	200%	0.055	0.0550	0.0825	0.1100
				Total Time:		0.2730	0.3073	0.3415

Pallet Pick-up

Activity	Distance/ occurrence	Allowance			Factor *	Computed times (minutes)		
		a	m	b		a	m	b
Stop	1	100%	75%	50%	0.0330	0.0330	0.0248	0.0165
Run-in	1	100%	100%	100%	0.0800	0.0800	0.0800	0.0800
Accelerate	1	100%	75%	50%	0.0250	0.0250	0.0188	0.0125
Back and stop	1	100%	150%	200%	0.0850	0.0850	0.1275	0.1700
Accelerate	1	100%	75%	50%	0.0250	0.0250	0.0188	0.0125
Left Forward	1	100%	150%	200%	0.055	0.0550	0.0825	0.1100
				Total Time:		0.3030	0.3523	0.4015

* Factor is based on a 2,000 lb pallet when carrying a load.

Table B-2. Standard data time estimates for pallet pick-up and drop-off times (Apple, 1972).

C. ELEVATOR OPERATIONS

A single test of the 12,000 lb elevator in hold #5 was conducted on the ship to estimate the elevator operating time. The time required to dispatch the elevator from the main deck to the second level was 23 seconds. Travelling at a rate of 100 feet per minute (per contract specifications) and traversing a vertical distance of 30 feet (average of 15 feet between decks) results in 18 seconds of travel time leaving 5 seconds for acceleration, deceleration, leveling-out, and opening and closing the door (referred to as elevator delay time). The test was run with all operators ready and no planned or unplanned delays introduced. Therefore this time represents a highly optimistic estimation rather than an average performance time.

APPENDIX C. OPERATING ENVIRONMENT FACTORS

A. SUMMARY OF FORKLIFT OPERATING VARIABLES

Table C-1 lists common factors which will reduce the operating efficiency of forklifts (Apple, 1972).

VARIABLE FACTOR	REASON FOR ALLOWANCE	METHOD OF ALLOWANCE	ASSESSMENT OF APPLICABILITY
Skill	Relative operator ability.	Estimated percent.	Moderate
Fatigue	Necessary rest time.	Generally 10%	Moderate
Carelessness	Lack of supervision.	Estimated locally.	Moderate
Distance	Too short to reach full speed.	Use ratio of capacity to useable speed.	High in holds.
Truck condition	Mechanical and electrical.	Develop percentage allowance.	Moderate
Battery	Power ebbs after 5 hrs.	Adjust per specifications.	Moderate
Traffic	Delays due to pedestrians and other trucks.	Locally estimate.	High
Obstructions	Low clearance, narrow aisles.	Locally estimated.	High in elevators.
Pavement	Type of surface.	Standard rates.	High in holds.
Loading area conditions	Combination of traffic, housekeeping, etc.	Apply individual factors.	High
Lighting	Basic motions assume 5 foot-candles.	Standard rates.	High
Housekeeping	Cluttered areas.	Locally estimated.	High
Scheduling	Time lost waiting for loads.	Determine proportion of time.	High
Temperature	Standard times based on 32 to 90 F.	Increase time by 10%	High
Weather	Rain reduces performance.	Increase time by 10%	Moderate
Aisle width	Basic times based on width of truck plus one foot.	Increase timed by 43% for fractions reduced.	High in elevators.
Two-way traffic	Basic times based on min 18" clearance.	Locally estimate.	Moderate
Doorways	Some require truck to slow.	Locally estimate.	High
Intersections	Affects increased if one aisle is narrow.	Estimate % of time.	High
Grades	Reduce speeds of electric trucks.	Increase straight runs 8% per % grade increase.	Low

APPENDIX D.   ELEVATOR MODEL (SIMAN PROGRAM)

A. PROGRAM MODEL AND EXPERIMENTAL FRAME

```
      BEGIN;
;
;   M. K. Fabish, 1994 - Model of elevator operations for the USNS SAN
JOSE
;

startup          ASSIGN: ns=storetype:        ! assigns sequence number
                 M=storetype:               ! assigns initial station
                 Grqty=GroupQty;   ! assigns # pallets in L

             BRANCH,1:
             IF,GroupQty.gt.1,multilift:
             ELSE,getlift;

multilift    QUEUE,GroupQ;                    [for carrying 1-3 pallets]
             GROUP:Grqty;

getlift      DELAY: ed(7);
             QUEUE, LiftQ;                     [Sequence to rqst Lift]
             REQUEST:Lift;
             TRANSPORT: Lift,SEQ,1.666667;

send         DELAY: ED(7);
             TRANSPORT: Lift,SEQ,1.666667; [Sends lift onward after stop at
hold]

     STATION, 1-4;       HOLD #X, Level M
        QUEUE, M;
        ASSIGN:Timein=TNOW;                       [Mark beginning of
flowtime]
        SEIZE: ForkTrk(M);                         [Utilization of
Hold3x Flift]
        delay:ED(GroupQty);                      [Time to load Lift3]
        RELEASE:ForkTrk(M):NEXT(send);   [Send Lift3 to main deck]

     STATION, MDatL;                                   [Main deck L
unloading routine]
        QUEUE,unloadQ;                         [Control Trk for
unloading]
        SEIZE: ForkTrkL;
        ASSIGN:TestQty=GroupQty;
        BRANCH,1:
          IF,GroupQty.gt.1,splitSEQ:
          ELSE,unload;
splitSEQ SPLIT:M;                                    [For multi
pallet loads only]
unload    QUEUE,unloadQ1;
        SEIZE: Equip;                             [Temp asset to
control flow]
        DELAY:ED(4+GroupQty-TestQty); [Time to pull Pallet from L]
        ASSIGN: TestQty=TestQty-1;
        BRANCH,1:
        IF,Nq(UnloadQ1).eq.0,LetgoL:
        ELSE,Final;
```

```
LetGoL     FREE:Lift;                              [Lift free to
move since empty]
          RELEASE:ForkTrkL;

Final     RELEASE:Equip;
          TALLY: 1,Hold_count;                    [Time for pallet to
reach main deck stage]
          Tally: 5,TNOW;
          COUNT:Hold_Count:DISPOSE;       [Pallet count out of hold]
END;

BEGIN;
;,,Y;   Step command for program validation
;EXPO FRAME
;  USS SAN JOSE ELEVATOR MODEL w/o embellishments
Project, USS SAN JOSE UNREP, M. K. Fabish   1994;

ATTRIBUTES:    Timein:
               StoreType:          ! Defines type of material and hold
origin
               GroupQty;

COUNTERS:      1, Hold_count,28;      !Counts # pallets out of hold

DISTRIBUTIONS: 1, UN(1,1):    !Load 1 pallet   on L
               2, UN(2,1):    !Load all 2 pallets on L
               3, UN(3,1):    !Load all 3 pallets on L
               4, UN(4,1):    !Remove 1st pallet from L
               5, UN(5,1):    !Remove 2nd pallet from L
               6, UN(6,1):    !Remove 3rd pallet from L
               7, UN(7,1);    !Elevator delay

PARAMETERS:    1, 18,36:
               2, 36,72:
               3, 55,110:
               4, 17,34:
               5, 21,42:
               6, 22,44:
               7, 5,7.5;

STATIONS:      HoldX1:
               HoldX2:
               HoldX3:
               HoldX4:
               MDatL;

RESOURCES:     Forktrk(4),1,1,1,1:   !Lift cap 1 pallet each level

               ForkTrkL:
               Equip;

QUEUES:        4:
               LiftQ:        ! ,     LVF(pri):
               GroupQ:
               TempQ:
               UnloadQ:         !Waiting for L# Ftrk
               UnloadQ1;
;
; list pallets pre-staged pallets in priority sequence, use a
; separate line for 3 pallet lifts and 1 or 2  pallet lifts
                    |
```

```
;_____|
;
;                                      qty      lvl GroupQty
;                                       |        |    |
ARRIVALS:       1,BLOCK(Startup),0.0,   6, 0.0, 1,   3: !create entity
                2,BLOCK(Startup),0.0,   3, 0.0, 4,   3:
                3,BLOCK(Startup),0.0,   9, 0.0, 2,   3:
                4,BLOCK(Startup),0.0,   9, 0.0, 3,   3:
                5,BLOCK(Startup),0.0,   1, 0.0, 3,   1;

SEQUENCES:      1,  HoldX1&MDatL:
                2,  HoldX2&MDatL:
                3,  HoldX3&MDatL:
                4,  HoldX4&MDatL;

TALLIES:        1,  Time Level 1 to MD,"here.sim":
                2,  Time Level 2 to MD:
                3,  Time Level 3 to MD:
                4,  Time Level 4 to MD:
                5,  T_Time;

OUTPUTS:        Tmax(T_time),"sev.sim",UNREP TIME;

TRANSPORTERS:   1,Lift,1,1,1.66667,5;          !Elevator in Hold to Main deck


VARIABLES:      GrQty:                  !Establishes Nr of pallets on L3
                TestQty;

DSTATS:         NR(1)*100,Util of FtruckX1:
                NR(2)*100,Util of FtruckX2:
                NR(3)*100,Util of FtruckX3:
                NR(4)*100,Util of FtruckX4:
                NR(ForkTrkL)*100,Util of Ftruck at MD L:
                NT(Lift)*100, Busy Elev;

;              Level2
;               |  Level3
;               |    |  Level4
;               |    |    |  Main Deck
;               |    |    |      |
;               |    |    |      |
DISTANCES: 1,1-5,  15,  30,  45,  15/ !from Level 1
                        15,  30,  30/ !from Level 2
                             15,  45/ !from Level 3
                                  60; !from Level 4
REPLICATE,100,0,5000,y,y,0;
End;
```

B. SAMPLE OUTPUT DATA

```
                    SIMAN IV - License #9050352
                      Naval Post-Graduate School

                  Summary for Replication 1 of 1

Project: USS SAN JOSE UNREP          Run execution date : 12/ 6/1994
Analyst: M.K.Fabish  1994            Model revision date: 12/ 6/1994

Replication ended at time     : 2060.57
                        TALLY VARIABLES

Identifier          Average   Variation   Minimum   Maximum   Observations

T_Time              1079.5    .56070      87.463    2060.6       28

                    DISCRETE-CHANGE VARIABLES

Identifier          Average   Variation   Minimum   Maximum   Final Value


Util of Ftruck31    8.1305    3.3615      .00000    100.00     .00000
Util of Ftruck32    13.108    2.5747      .00000    100.00     .00000
Util of Ftruck33    12.868    2.6022      .00000    100.00     .00000
Util of Ftruck34    3.9914    4.9045      .00000    100.00     .00000
Util of Ftruck at MD 37.832   1.2819      .00000    100.00     .00000
Busy Elev           99.755    .04952      .00000    100.00     .00000

                              COUNTERS
```

Identifier	Count	Limit
Hold_count	28	28

```
                              OUTPUTS
```

Identifier	Value
UNREP TIME	2060.6

```
Simulation run complete.
```

APPENDIX E. CARGO DELIVERY MODEL (SIMAN PROGRAM)

A. PROGRAM MODEL AND EXPERIMENTAL FRAME

```
BEGIN;_____
;  M.K. Fabish - 1994 Cargo delivery for USNS SAN JOSE
;_____

startup         ASSIGN: ns=Origin:    ! assigns sequence number
                       M=Origin:      ! assigns initial station
                       Grqty=GroupQty; ! assigns # pallets in L

             BRANCH,1:
             IF,GroupQty.gt.1,multilift:
             ELSE,picklift;

multilift    QUEUE,GroupQ;                  for Multi load embellishment
          GROUP:Grqty;

picklift     BRANCH,1:
             IF,Origin.LT.5,getlift3:
             IF,Origin.LT.10,getlift4;

getlift3     QUEUE, Lift3Q;                Sequence to rqst Lift3
          REQUEST:Lift3;
          TRANSPORT: Lift3,SEQ,100;
getlift4     QUEUE, Lift4Q;                Sequence to rqst Lift4
          REQUEST:Lift4;
          TRANSPORT: Lift4,SEQ,10;

send            BRANCH,1:
             IF,Origin.LT.5,sendlift3:
             IF,Origin.LT.10,sendlift4;

sendlift3    DELAY:ED(13);
          TRANSPORT: Lift3,SEQ,100; Sends lift onward from hold

sendlift4    DELAY:ED(13);
          TRANSPORT: Lift4,SEQ,100; Sends lift onward from hold

    STATION, 1-8;      HOLD #3-#5,
       QUEUE, M;
       ASSIGN:Timein=TNOW;                [Mark beginning of flowtime]
       SEIZE: ForkTrk(M);                      [Utilization of Hold3x
Flift]
       DELAY:ED(GroupQty);                [Time to load Lift3]
       RELEASE:ForkTrk(M):NEXT(send); [Send Lift3 to main deck]
;_____

    STATION, MDatL3;                       [Main deck L3 unloading
routine]
       QUEUE,unload3Q;                 [Contol Trk for unloading]
       SEIZE: ForkTrkL3;
       ASSIGN:TestQty3=GroupQty;
       BRANCH,1:
         IF,GroupQty.gt.1,split3SEQ:
         ELSE,unload3;
split3SEQ SPLIT:M;                         [for multi pallet loads
```

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```
only]
unload3    QUEUE,unload3Q1;
           SEIZE: Equip3;                      [Temp asset to control flow]
           DELAY:ED(4+GroupQty-TestQty3)*.4; [Time to pull Pallet from L3]
           QUEUE,L3StageQ1;
           SEIZE:L3Staging;
           DELAY:ED(4+GroupQty-TestQty3)*.2; [Time in control of stage
area]
           RELEASE:L3Staging;
           DELAY:ED(4+GroupQty-TestQty3)*.4;                     [Time to
move towards L3]
           ASSIGN: TestQty3=TestQty3-1;
           BRANCH,1:
           IF,Nq(Unload3Q1).eq.0,LetgoL3:
           ELSE,Moveon3;

LetGoL3    FREE:Lift3;                  [Lift free to move since empty]
           RELEASE:ForkTrkL3;

Moveon3    RELEASE:Equip3;
           COUNT:Hold3_Count;           Pallet count out of hold3
           ASSIGN: NS=9;                !Reset all NS for 2nd
transporter
                IS=1;
           ROUTE:0,L3Stage;

STATION, L3Stage;

           QUEUE, ForkTrkAft3Q;                 Q for delivery to RASsta
           ALLOCATE: FTruckMD3(SDS,FTruck#);

ChkPos3    BRANCH,1:
           IF,M.eq.11.and.LT(FtruckMD3,FTruck#).eq.11,Load3:
           IF,M.eq.11.and.LT(FtruckMD3,FTruck#).ne.11,ToL3;

ToL3       BRANCH,1:
            IF,M.eq.Fwd1Lane,onward3:
            ELSE,ToL3comp;
onward3     ASSIGN:MDFTSpeed= ED(7);
           MOVE:FtruckMD3(FTruck#),L3Stage,MDFTSpeed:
           NEXT(Load3);
ToL3comp    ASSIGN:MDFTSpeed=ED(10);
           MOVE:FtruckMD3(FTruck#),Aft1Lane,MDFTSpeed;
           QUEUE, Aisle3Q1;
           SEIZE: NAisle;                       Narrow Aisle
           ASSIGN:MDFTSpeed=ED(9)*.3;
           MOVE:FtruckMD3(FTruck#),Fwd1Lane,MDFTSpeed;
           RELEASE:NAisle;
           ASSIGN:MDFTSpeed=ED(7);
           MOVE:FtruckMD3(FTruck#),L3Stage,MDFTSpeed:NEXT(load3);
Load3       BRANCH,1:
            IF,M.eq.11,GetAisle3:
            ELSE,Dest3;
GetAisle3  QUEUE,L3StageQ2;
           SEIZE:L3Staging;             [Occupy the staging area]
           DELAY:ED(12);
           RELEASE:L3Staging;
           ASSIGN:MDFTSpeed=ED(7);
           MOVE:FtruckMD3(FTruck#),Fwd1Lane,MDFTSpeed;
           QUEUE,Aisle3Q3;
           SEIZE:NAisle;
```

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```
          ASSIGN:MDFTSpeed=ED(9)*.8;
          MOVE:FTruckMD3(FTruck#),Aft1Lane,MDFTSpeed;
          RELEASE:NAisle;
Dest3     ASSIGN:MDFTSpeed=ED(10);
          TRANSPORT:FTruckMD3(FTruck#),SEQ,MDFTSpeed;


;_____


     STATION, MDatL4;                [Main deck L3 unloading routine]
        QUEUE,unload4Q;              [Contol Trk for unloading]
        SEIZE: ForkTrkL4;
        ASSIGN:TestQty4=GroupQty;
        BRANCH,1:
          IF,GroupQty.gt.1,splitSEQ4:
          ELSE,unload4;
splitSEQ4 SPLIT:M;                   [for multi pallet loads only]

unload4   QUEUE,unload4Q1;
          SEIZE: Equip4;             [Temp asset to control flow]
          DELAY:ED(4+GroupQty-TestQty4)*.4; [Time to pull Pallet from L3]
          QUEUE,L4StageQ1;
          SEIZE:L4Staging;
          DELAY:ED(4+GroupQty-TestQty4)*.2;   [Time in control of stage
area]
          RELEASE:L4Staging;
          DELAY:ED(4+GroupQty-TestQty4)*.4;   [Time to move towards L4]
          ASSIGN: TestQty4=TestQty4-1;
          BRANCH,1:
          IF,Nq(Unload4Q1).eq.0,LetgoL4:
          ELSE,Moveon4;


LetGoL4   FREE:Lift4;                [Lift free to move since empty]
          RELEASE:ForkTrkL4;


Moveon4   RELEASE:Equip4;
          COUNT:Hold4_Count;         Pallet count out of hold3
          ASSIGN: NS=10:                !Reset all NS for 2nd
transporter
               IS=1;
          ROUTE:0,L4Stage;


     STATION, L4Stage;
          QUEUE, ForkTrkAft4Q;                Q for delivery to RASsta
          ALLOCATE: FTruckMD4(SDS,FTruck#);


ChkPos4   BRANCH,1:
          IF,M.eq.12.and.LT(FtruckMD4,FTruck#).eq.12,Load4:
          IF,M.eq.12.and.LT(FtruckMD4,FTruck#).ne.12,ToL4;


ToL4      BRANCH,1:
          IF,M.eq.Fwd1Lane,onward4:
          ELSE,ToL4Comp;
onward4    ASSIGN:MDFTSpeed=ED(8);
          MOVE:FtruckMD4(FTruck#),L4Stage,MDFTSpeed:
          NEXT(Load4);
ToL4comp   ASSIGN:MDFTSpeed=ED(10);
          MOVE:FtruckMD4(FTruck#),Aft1Lane,MDFTSpeed;
          QUEUE, Aisle4Q1;
          SEIZE: NAisle;                      Narrow Aisle
          ASSIGN:MDFTSpeed=ED(9)*.8;
          MOVE:FtruckMD4(FTruck#),Fwd1Lane,MDFTSpeed;
```

```
          RELEASE:NAisle;
          ASSIGN:MDFTSpeed=ED(8);
          MOVE:FtruckMD4(FTruck#),L4Stage,MDFTSpeed:NEXT(load4);
Load4     BRANCH,1:
          IF,M.eq.12,GetAisle4:
          ELSE,Dest4;
GetAisle4  QUEUE,L4StageQ2;
          SEIZE:L4Staging;                  [Occupy the staging area]
          DELAY:ED(12);
          RELEASE:L4Staging;
          ASSIGN:MDFTSpeed=ED(8);
          MOVE:FtruckMD4(FTruck#),Fwd1Lane,MDFTSpeed;
          QUEUE,Aisle4Q3;
          SEIZE:NAisle;
          ASSIGN:MDFTSpeed=ED(9)*.8;
          MOVE:FTruckMD4(FTruck#),Aft1Lane,MDFTSpeed;
          RELEASE:NAisle;
Dest4     ASSIGN:MDFTSpeed=ED(10);
          TRANSPORT:FTruckMD4(FTruck#),SEQ,MDFTSpeed;
;_____

     STATION,  Fwd1Lane;
     STATION,  Aft1Lane;
     STATION,  FreeTrk3;
        DELAY: ED(11);                 Time to unload at AftCargo
        FREE:  FTruckMD3(FTruck#);     Free Flift for next pallet
        ROUTE: 0,Aftcargo;

     STATION,  FreeTrk4;
        DELAY: ED(11);                 Time to unload at AftCargo
        FREE:  FTruckMD4(FTruck#);     Free Flift for next pallet
        ROUTE: 0,Aftcargo;

     STATION,Aftcargo;
        QUEUE, AftCargoQ;
        SEIZE: AftStage;
        DELAY: 0;
        TALLY: 2,TNOW;
        COUNT: AftCargo_count;
        RELEASE:Aftstage:dispose;

END;

BEGIN;
;,,Y;     Step command for program validation
;EXPO FRAME
;   USS SAN JOSE with L3 and L4 embellishments
Project, USS SAN JOSE UNREP, M. K. Fabish      1994;

ATTRIBUTES:     Timein:
                Origin:       ! Defines hold/level origin
                GroupQty:     ! Defines Nr pallets on Lift
                FTruck#;      ! Used to assign Ftrk

COUNTERS:       1, Hold3_count:    !Counts # pallets out of hold 3
                2, Hold4_count:    !                              4
                3, AftCargo_Count,68; Total Pallets for AfterCargo

DISTRIBUTIONS:  1, UN(1,1):   !Load 1 pallet  on L3
                2, UN(2,1):   !Load 2 pallets on L3
                3, UN(3,1):   !Load 3 pallets on L3
                4, UN(4,1):   !Remove 1st pallet from L3
```

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```
                5, UN(5,1):     !Remove 2nd pallet from L3
                6, UN(6,1):     !Remove 3rd pallet from L3
                7, UN(7,1):     !Trk speed L3 to FwdlLane
                8, UN(8,1):     !Trk speed L4 to FwdlLane
                9, UN(9,1):     !Trk speed Narrow Aisle
               10, UN(10,1):    !Trk Speed in After cargo
               11, UN(11,1):    !Time to unload at AftCargo
               12, UN(12,1):    !Time MD ftrk controls L stage area
               13, UN(13,1);

PARAMETERS:     1,    .3, .6:
                2,    .6, 1.2:
                3,    .92, 1.84:
                4,    .29, .58:
                5,    .35, .70:
                6,    .37, .74:
                7,    172, 258:
                8,    172, 258:
                9,    172, 258:
               10,    172, 258:
               11,    .27, .54:
               12,    .27, .54:
               13,    .083,.166;

STATIONS:       1, Hold31:      ! 1-4 =#3, 5-8=#4,9-12=#5
                4, Hold34:
                9, MDatL3:
               10,MDatL4:
               11,L3stage:
               12,L4stage:
               13,FwdlLane:
               14,AftlLane:
               15,FreeTrk3:
               16,FreeTrk4:
               17,AftCargo;

RESOURCES:      Forktrk(8):  !Lift cap 1 pallet each hold3_
                ForkTrkL3:
                ForktrkL4:
                AftStage,2:
                NAisle,1:
                L3Staging:
                L4Staging:
                Equip3:    ! Artificial delays for flow reasons
                Equip4;

QUEUES:         8:
                ForkTrkAft3Q:
                ForkTrkAft4Q:
                Lift3Q:          !,     LVF(pri):
                Lift4Q:
                Aisle3Q1:          !Waiting for Aisle going Fwd (empty)
                Aisle3Q3:          !Waiting for Aisle going Aft (Full)
                Aisle4Q1:          !Waiting for Aisle going Fwd (empty)
                Aisle4Q3:          !Waiting for Aisle going Aft (Full)
                GroupQ:
                TempQ:
                L3StageQ1:       !L3Ftrk waiting for L3 stage area
                L3StageQ2:       !FTruckMD waiting for L# stage area
                L4StageQ1:
                L4StageQ2:
```

```
                    Unload3Q:        !Waiting for L# Ftrk
                    Unload3Q1:
                    Unload4Q:        !Waiting for L# Ftrk
                    Unload4Q1:
                    AftCargoQ;
;_____
; list pallets pre-staged pallets in priority sequence, use a
; separate line for 3 pallet lifts and 1 or 2  pallet lifts      |
;_____|
;
;                            qty      origin GpQty  Truck#
;                     |    |    |       |        |      |
ARRIVALS:  1,BLOCK(Startup),0.0, 6,  .0,    1,    3,     0: ! create
entity
           2,BLOCK(Startup),0.0, 3,  .0,    4,    3,     0:
           3,BLOCK(Startup),0.0, 9,  .0,    2,    3,     0:
           4,BLOCK(Startup),0.0, 9,  .0,    3,    3,     0:
           5,BLOCK(Startup),0.0, 1,  .0,    3,    1,     0:
           6,BLOCK(Startup),0.0, 12, .0,    5,    3,     0: ! create
entity
           7,BLOCK(Startup),0.0, 15, .0,    6,    3,     0:
           8,BLOCK(Startup),0.0, 9,  .0,    7,    3,     0:
           9,BLOCK(Startup),0.0, 1,  .0,    7,    1,     0:
          10,BLOCK(Startup),0.0, 3,  .0,    8,    3,     0;

SEQUENCES:       1, Hold31&MDatL3:
                 2, 2&MDatL3:
                 3, 3&MDatL3:
                 4, 4&MDatL3:
                 5, 5&MDatL4:
                 6, 6&MDatL4:
                 7, 7&MDatL4:
                 8, 8&MDatL4:
                 9, Aft1Lane&FreeTrk3:
                10, Aft1Lane&FreeTrk4;

TALLIES:         1, FWDwait,"fwd.sim":
                     2, T_Time;


OUTPUTS: TMAX(T_Time),"time.sim",UNREP TIME:
         DAVG(16),"UTIL.SIM",MDFTUTIL:
         DAVG(2), "back.sim",back;

TRANSPORTERS:  1,Lift3,1,1,100,9:        !Elevator from Hold3X to Deck
(EL3)
               2,Lift4,1,1,100,10:       !Elevator from Hold4X to Deck
(EL4)
               3,FTruckMD3,1,2,5,11:     !Flifts from L3Stage to Aft Cargo
               4,FTruckMD4,2,3,5,12;     !Flifts from L4Stage to Aft Carg

VARIABLES:     GrQty:              !Establishes Nr of pallets on L3
                     TestQty3:
                     TestQty4:
                     MDFTSpeed;

DSTATS:        NQ(ForkTrkAft3Q),Nr. waiting MDL3 Ftrks,"MDFT3.sim":
               NQ(ForkTrkAft4Q),Nr. waiting MDL4 Ftrks,"MDFT4.sim":
               NQ(AftCargoQ), Nr. staged at RASsta10:
               NQ(Aisle3Q1),Waiting Aisle going Fwd:
               NQ(Aisle3Q3),Waiting Aisle going Aft:
```

```
                  NQ(L3StageQ1),L3Trk wait for L3Stage:
                  NQ(L3StageQ2),MDFtrk wait for L3Stage:
                  NR(1)*100,Util of Ftruck31:
                  NR(2)*100,Util of Ftruck32:
                  NR(3)*100,Util of Ftruck33:
                  NR(4)*100,Util of Ftruck34:
                  NR(ForkTrkL3)*100,Util of FtruckEl3:
                  NR(ForkTrkL4)*100,Util of FtruckEl4:
                  NT(Lift3)*100, Busy Elev 3:
                  NT(FtruckMD3)*100,Busy Forktrkl3:
                  NT(FtruckMD4)*100,Busy Forktrkl4;

DISTANCES: 1,9-1-15,9-2-30,9-3-45,9-4-60,
           10-5-15,10-6-30,10-7-45,10-8-60:
         2,11-13-175,13-14-60,14-15-35,11-15-100000:
         3,12-13-20,13-14-60,14-16-35,12-16-1000000;

REPLICATE,50,0,5000,y,y,0;
;TRACE,,,ns;
END;
```

B. SAMPLE OUTPUT DATA

```
                   SIMAN IV - License #9010699
                    Naval Post-Graduate School

                  Summary for Replication 1 of 1

Project:  USS SAN JOSE UNREP          Run execution date :  12/ 6/1994
Analyst:  M.K.Fabish    1994          Model revision date:  12/ 6/1994

Replication ended at time      : 100.439

                      TALLY VARIABLES
```

Identifier	Average	Variation	Minimum	Maximum	Observations
T_Time	28.467	.55222	3.4552	55.849	40

```
                  DISCRETE-CHANGE VARIABLES
```

Identifier	Average	Variation	Minimum	Maximum	Final Value
Nr.waiting MDL3 Ftrks	8.5290	.61567	.00000	18.000	.00000
Nr.waiting MDL4 Ftrks	.10666	2.8940	.00000	1.0000	.00000
Nr.staged at RASsta10	.00000	--	.00000	.00000	.00000
Waiting Aisle going Fw	.00745	11.545	.00000	1.0000	.00000
Waiting Aisle going Af	.01906	7.1733	.00000	1.0000	.00000
L3Trk wait for L3Stage	.01045	9.7296	.00000	1.0000	.00000
MDFtrk wait for L3Stag	.00000	--	.00000	.00000	.00000
Util of Ftruck31	2.4658	6.2892	.00000	100.00	.00000
Util of Ftruck32	3.4462	5.2932	.00000	100.00	.00000
Util of Ftruck33	5.2553	4.2460	.00000	100.00	.00000
Util of Ftruck34	1.2386	8.9296	.00000	100.00	.00000
Util of Ftruck41	4.3328	4.6989	.00000	100.00	.00000
Util of Ftruck42	7.6896	3.4648	.00000	100.00	.00000
Util of Ftruck43	4.4497	4.6339	.00000	100.00	.00000
Util of Ftruck44	1.1309	9.3501	.00000	100.00	.00000
Util of FtruckEl3	15.097	2.3714	.00000	100.00	.00000
Util of FtruckEl4	24.127	1.7733	.00000	100.00	.00000
Busy Elev 3	35.947	1.3349	.00000	100.00	.00000
Busy Forktrkl3	98.082	.13983	.00000	100.00	.00000
Busy Forktrkl4	85.348	1.0291	.00000	200.00	.00000

```
                         COUNTERS
```

Identifier	Count	Limit
Hold3_count	23	Infinite
Hold4_count	40	Infinite
AftCargo_Count	68	68

OUTPUTS

Identifier	Value
UNREP TIME	55.849
MDFTUTIL	15.097
BACKLOG at Elevator #3	.10666

Run Time: 0 min(s) 1 sec(s)
Simulation run complete.

APPENDIX F. SIMULATION OUTPUT SUMMARY

A. SUMMARY STATISTICS FOR HOLD #3 ELEVATOR OPERATIONS

ELEVATOR #3 Performance Data

Favorable Elevator Operating Conditions

Forklift Speed:High				Forklift Speed:Medium				Forklift Speed:Slow			
Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue
1	65.1	97%	7.31	1	71.2	98%	7.83	1	98.5	98%	9.32
2	34.8	91%	1.21	2	37.9	92%	1.97	2	51.1	95%	4.65
3	30.6	68%	0.001	3	30.9	75%	0.007	3	37.1	87%	0.993

Normal Elevator Operating Conditions

Forklift Speed:High				Forklift Speed:Medium				Forklift Speed:Slow			
Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue
1	65.7	97%	5.8	1	71.6	97%	6.45	1	97.2	98%	8.36
2	39.8	80%	0.268	2	40	87%	0.495	2	52.1	93%	3.03
3	39.4	53%	0	3	38.8	59%	0	3	40.2	80%	0.075

Severe Elevator Operating Conditions

Forklift Speed:High				Forklift Speed:Medium				Forklift Speed:Slow			
Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue
1	63.8	96%	3.59	1	69.6	96%	4.4	1	98.5	97%	6.86
2	47.8	64%	0.109	2	48.9	69%	0.141	2	51.8	90%	0.874
3	48	42%	0.109	3	48.9	45%	0	3	49	62%	0

* Based on 28 pallet sample UNREP requirement.

B. SUMMARY STATISTICS FOR HOLD #4 ELEVATOR OPERATIONS

ELEVATOR #4 Performance Data

Favorable Elevator Operating Conditions

Forklift Speed:High				Forklift Speed:Medium				Forklift Speed:Slow			
Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue
1	52.1	97%	4.89	1	56	97%	5.88	1	73.7	98%	9.22
2	41.4	61%	0.113	2	42.1	64%	0.125	2	42.7	84%	0.371

Normal Elevator Operating Conditions

Forklift Speed:High				Forklift Speed:Medium				Forklift Speed:Slow			
Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue
1	61.5	96%	3.29	1	65.3	97%	4.2	1	83.3	97%	7.53
2	52	57%	0.09	2	52.3	60%	0.099	2	55.3	73%	0.165

Severe Elevator Operating Conditions

Forklift Speed:High				Forklift Speed:Medium				Forklift Speed:Slow			
Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue	Assigned Forklifts	UNREP Time (min)	Delivery Truck Utilization	Elevator Stage Queue
1	65.8	89%	0.311	1	68	93%	0.896	1	83.3	97%	7.53
2	65.6	45%	0.021	2	65.8	50%	0.039	2	66.9	62%	0.116

* Based on 40 pallet sample UNREP requirement.

APPENDIX G. NARROW AISLE STATISTICS SUMMARY

A. SUMMARY OF FORKLIFT OPERATING VARIABLES

Table G-1 list results of increase in the total time to complete cargo delivery operation due to the traffic congestion caused by the narrow aisle.

One forklift assigned to each hold

Aisle Status	Fast			Medium			Slow		
	Lower Range	Mean	Upper Range	Lower Range	Mean	Upper Range	Lower Range	Mean	Upper Range
w/Narrow Aisle	61.4	62.6	64.1	65.1	67.1	69.2	84.9	86.9	88.6
w/o Narrow Aisle	60.0	61.5	63.3	63.4	65.3	67.2	82.0	83.3	84.9
Difference	1.4	1.1	0.8	1.7	1.8	2.0	2.9	3.6	3.7

Two forklifts assigned to each hold

Aisle Status	Lower Range	Mean	Upper Range	Lower Range	Mean	Upper Range	Lower Range	Mean	Upper Range
w/Narrow Aisle	50.4	52.3	54.8	50.9	52.8	55.0	52.0	55.7	57.8
w/o Narrow Aisle	50.0	52.0	53.9	50.2	52.3	54.1	51.4	55.3	57.7
Difference	0.4	0.3	0.9	0.7	0.5	0.9	0.6	0.4	0.1

* Based on normal conditions for elevator.

Worst Case: Two forklifts assigned to Hold #3 and one forklift assigned to Hold #4

Aisle Status	Lower Range	Mean	Upper Range
w/Narrow Aisle	76.6	78.8	81.0
w/o Narrow Aisle	72.9	73.7	75.2
Difference	3.7	5.1	5.8

* Based on favorable conditions for elevator and slow speeds for forklifts.

Table G-1. Impact of narrow aisle on total cargo handling time for holds #3 and #4 in minutes.

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